

Recent Developments in Gas Detector Technologies: Possible Applications in PHENIX

Klaus Dehmelt (Stony Brook Univ.)

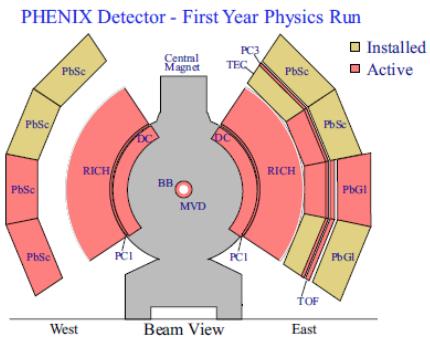
PHENIX December Decadal R&D Workshops
Tracking (GEMs, Si, etc.)
December 15th, 2010

Overview

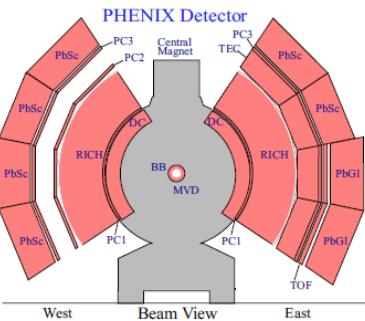
- PHENIX Detector Evolution
- sPHENIX Midrapidity/Forward Upgrades
- Gaseous Detectors
- Micro Pattern Gas(eous) Detectors MPGD
- MPGD Readout
- Possible Applications
 - **PHENIX Detector Evolution**
 - **sPHENIX Midrapidity/Forward Upgrades**

PHENIX: Detector Evolution

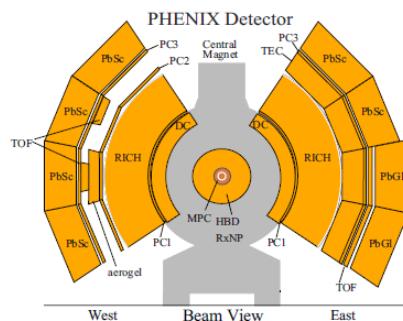
2000



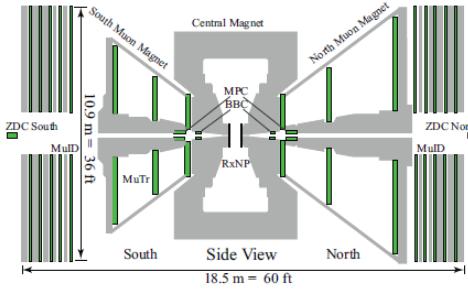
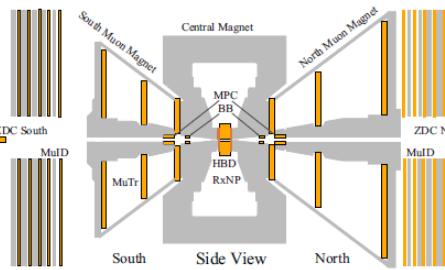
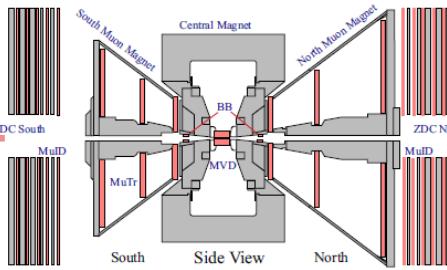
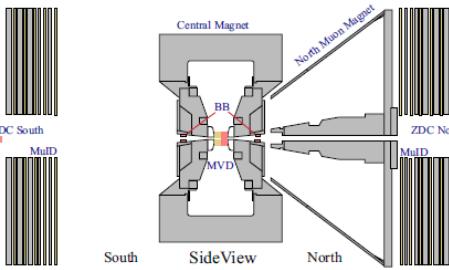
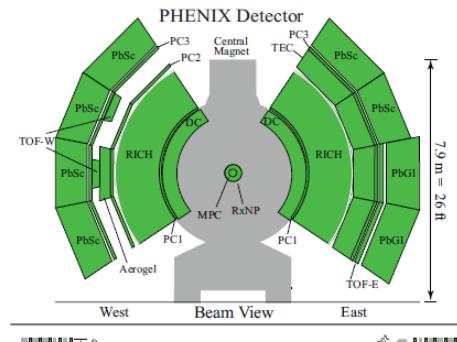
2003



2007



2008



In almost all runs: central tracking system included

PHENIX: Detector Evolution

- ◆ Central Tracking system:
 - Drift Chambers (DC)
 - Pad Chambers (PC)
 - Time Expansion Chamber (TEC)
- ◆ Tracking system's age > 10 years
- ◆ Based on wire chambers
- ◆ Requires regular program of maintenance and repair
 - e.g. replacement of one of the 16 PC1 modules; major servicing to West PCs

PHENIX: Detector Evolution

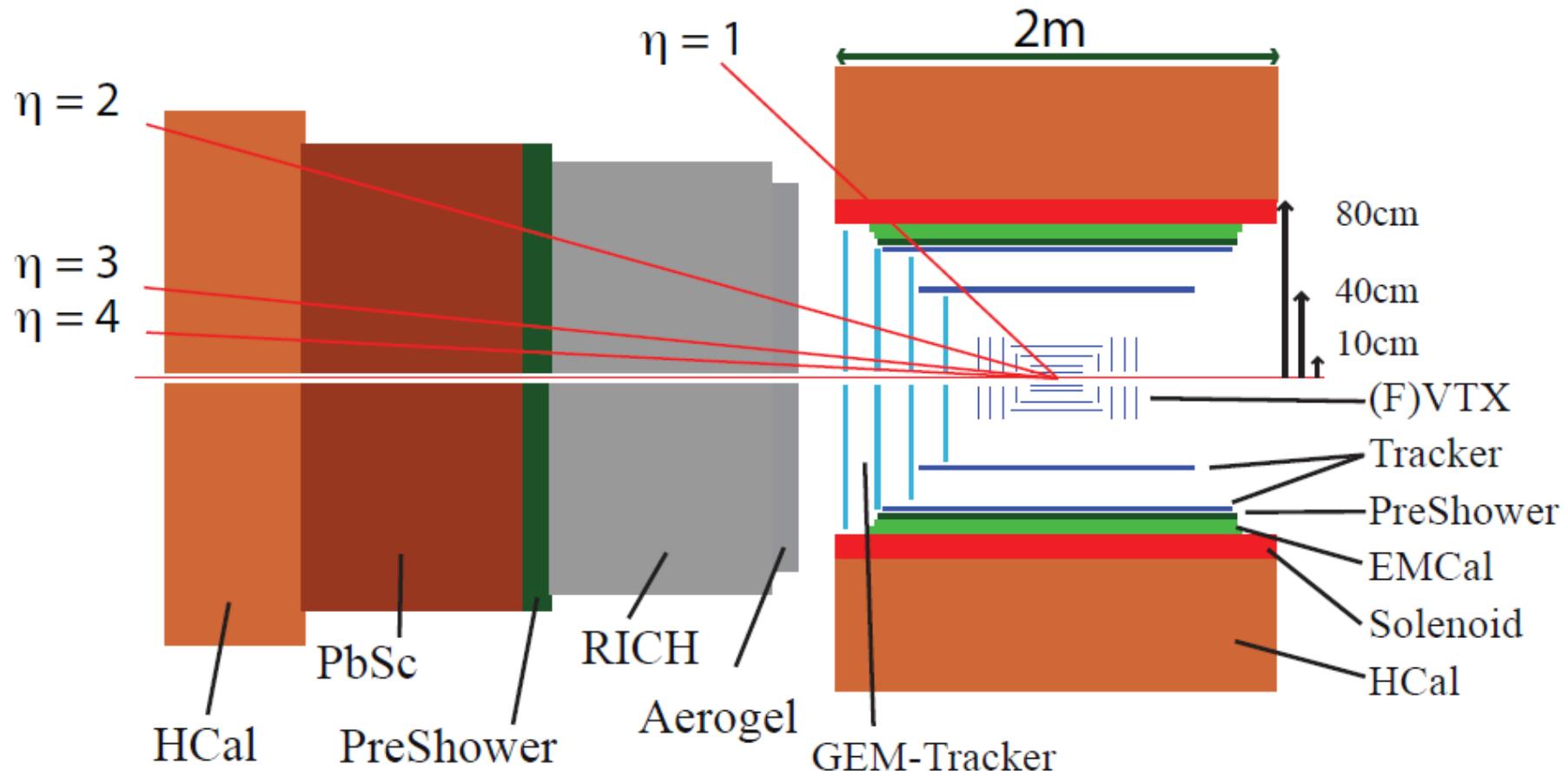
Central Tracking system still in good condition for future runs → options are being considered to:

- Maintain high level of operating efficiency
- Improvement of overall tracking performance

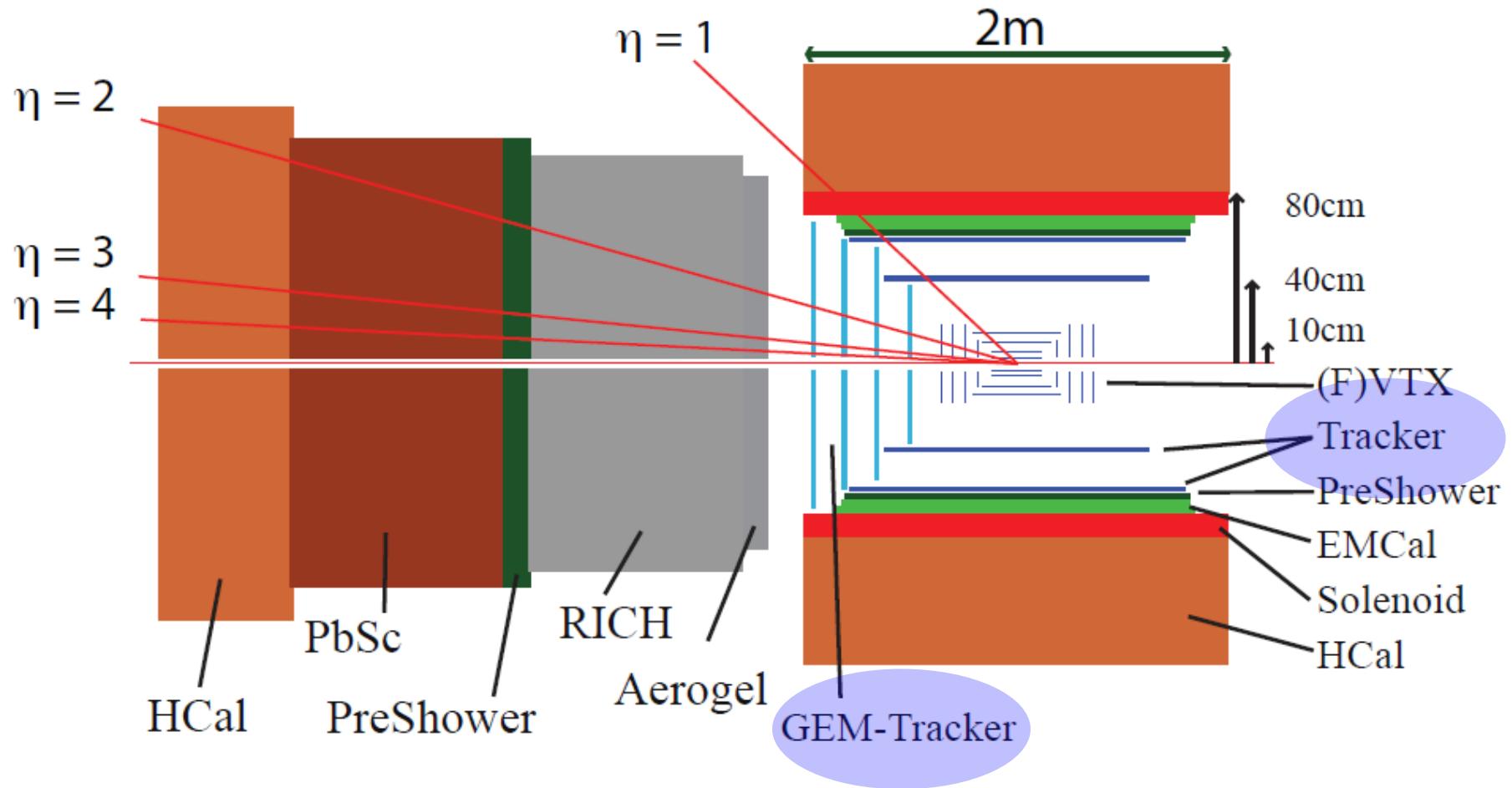
Options are:

- Additions to the central tracking system
- Replacement of wire chambers with GEM detectors

sPHENIX: Tracker Upgrades



sPHENIX: Tracker Upgrades



sPHENIX: Midrapidity Upgrades

High segmentation and spatial resolution:
Improvement of momentum resolution for higher momentum
tracks, ability for background rejection, identification of
decays.

Detector	Technology	Segmentation	R (cm)	N_{chan} ($\times 10^6$)
Outer Tracking	New Strips	$80 \mu\text{m} \times 3 \text{ cm}$	40	1
			60	2.2

Material budget, electronic readout requirements and costs:
Technology option could be gaseous detectors like
Micro Pattern Gas Detectors (MPGD)

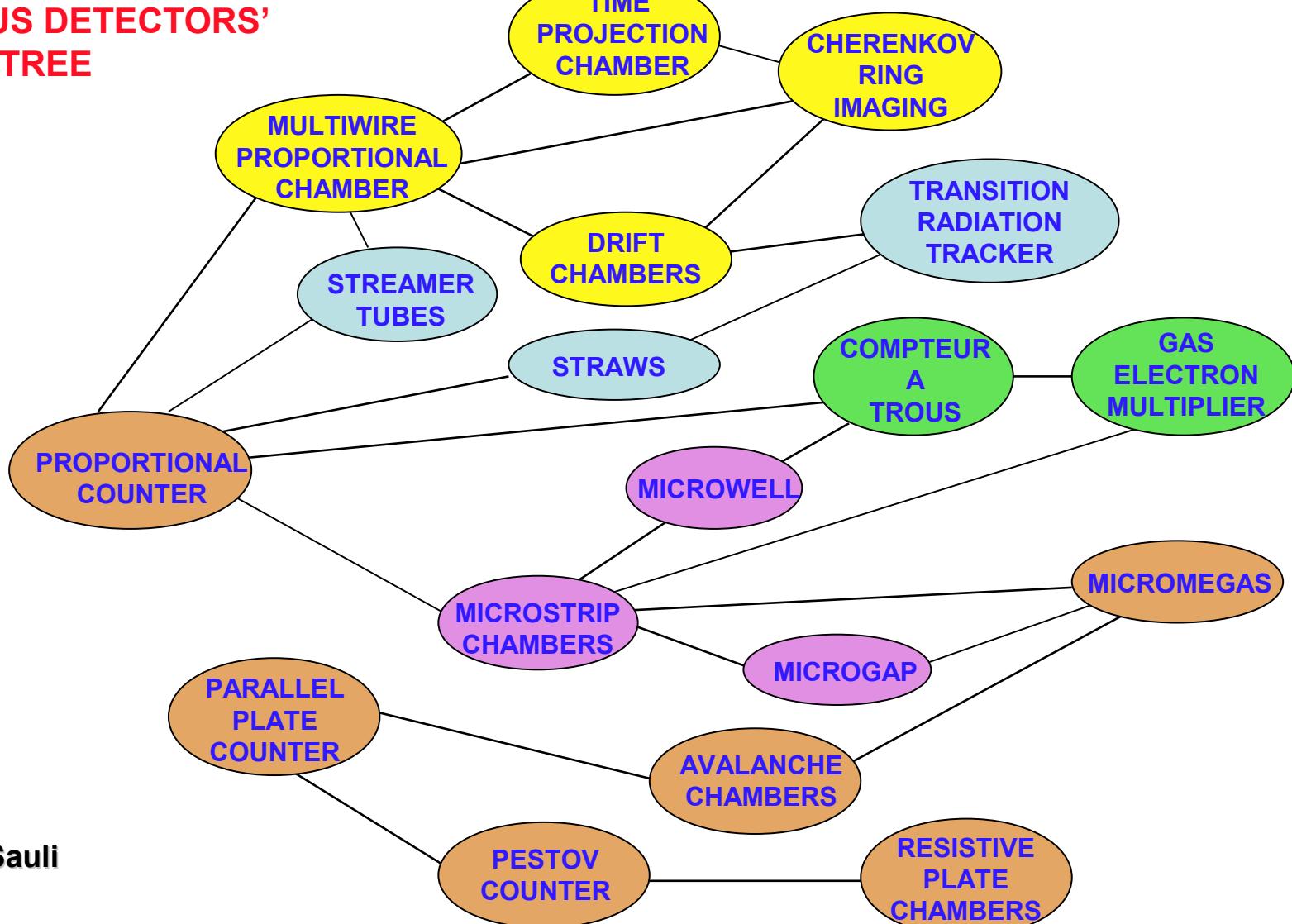
sPHENIX: Forward Upgrades

Keep integrated radiation length to a minimum to avoid bremsstrahlung as much as possible;
good position resolution for tracks at low angles

Rather large area to be covered;
material budget, electronic readout requirements and costs:
Micro Pattern Gas Detectors (MPGD) will be perfect solution

Gaseous Detectors

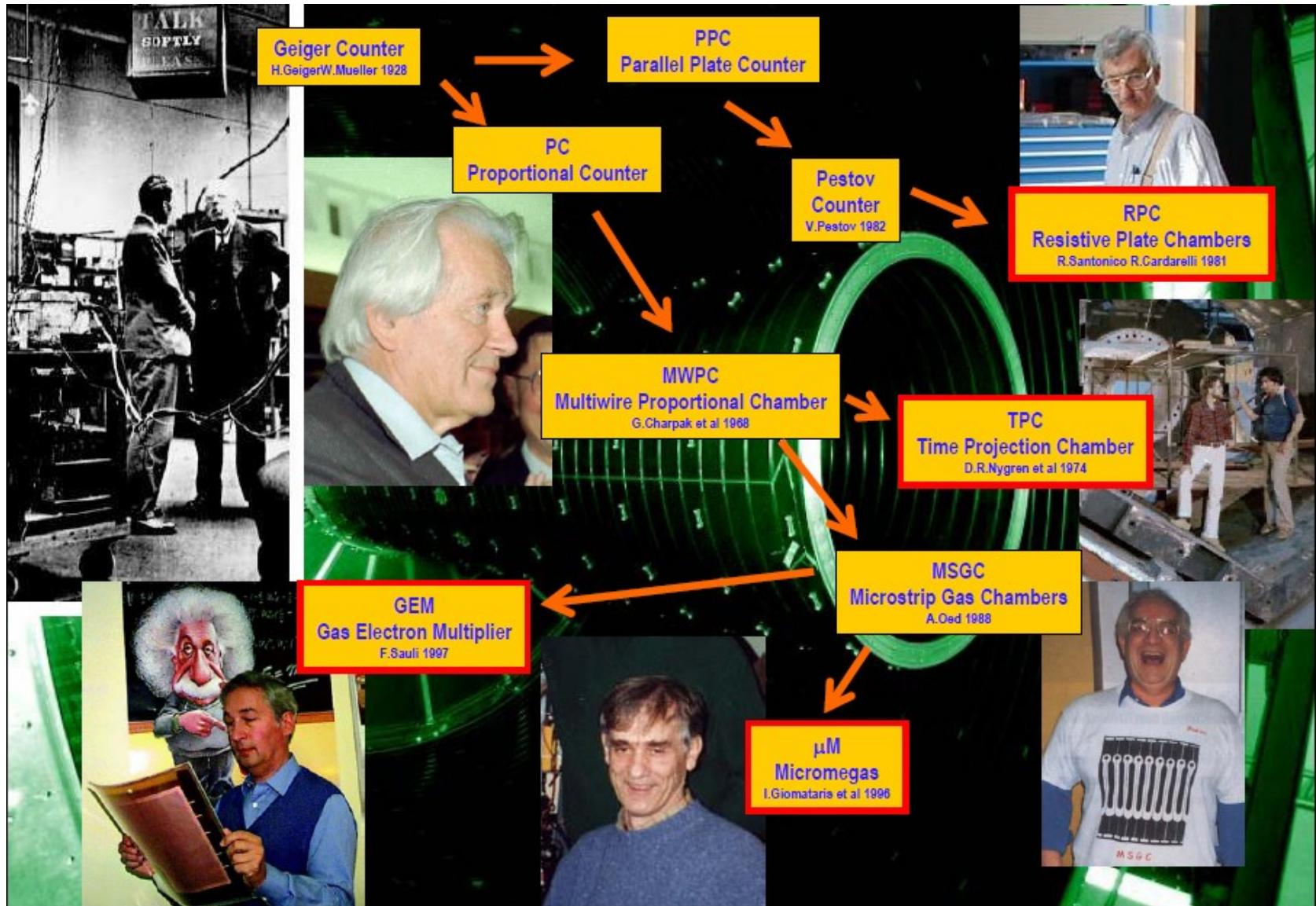
GASEOUS DETECTORS' FAMILY TREE



Fabio Sauli

Gaseous Detectors

M. Hoch



Gaseous Detectors

- Why to use Gaseous Detectors
 - Good spatial resolution
 - Fast and big signals
 - dE/dx
 - High rate capability
 - Flexible and convenient detector configurations
 - Low material budget
 - Large and cost friendly area coverage

MAIN DISADVANTAGE OF GASEOUS AS COMPARED TO SOLID STATE DETECTORS:

THEY MUST BE MANUFACTURED BY THE USERS

MAIN ADVANTAGE OF GASEOUS AS COMPARED TO SOLID STATE DETECTORS:

THEY CAN BE MANUFACTURED BY THE USERS!

Fabio Sauli:

Gaseous Detectors

- Gaseous detectors at LHC:

ALICE:

MWPC TPC as main tracker
TRD with straws

Muon Detector with pad chambers/
resistive plate chambers (RPC)
TOF with MRPC
HMPID with RICH-pad chamber

LHCb:

Tracker with straws
Muon Detector with
MWPC/GEM

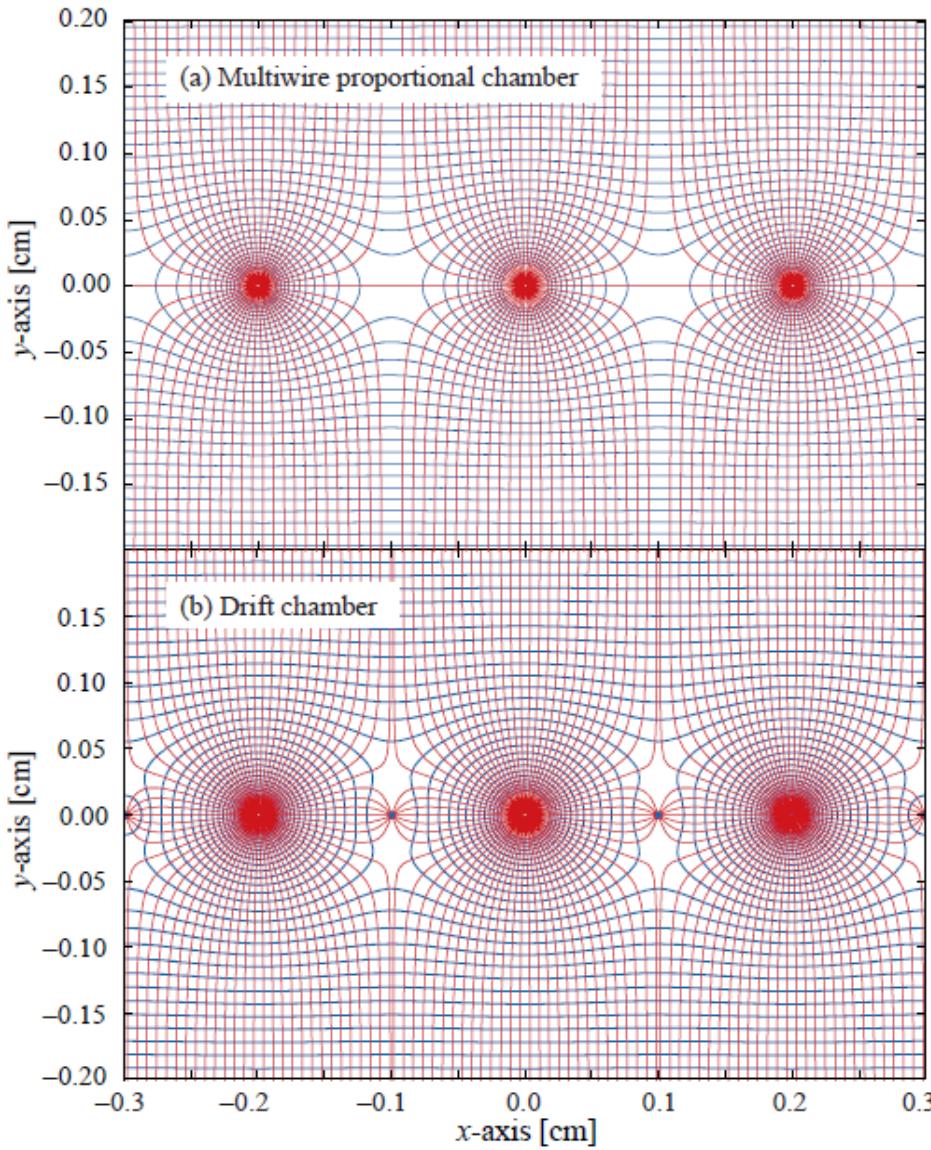
CMS:

Muon Detector with drift tubes/
cathode strip chambers (CSC)/
resistive plate chambers (RPC)
TOTEM Tracker with GEM

ATLAS:

TRD with straws
Muon Detector with drift tubes
(MDT)/thin gap chamber (TGC)/
resistive plate chambers (RPC)

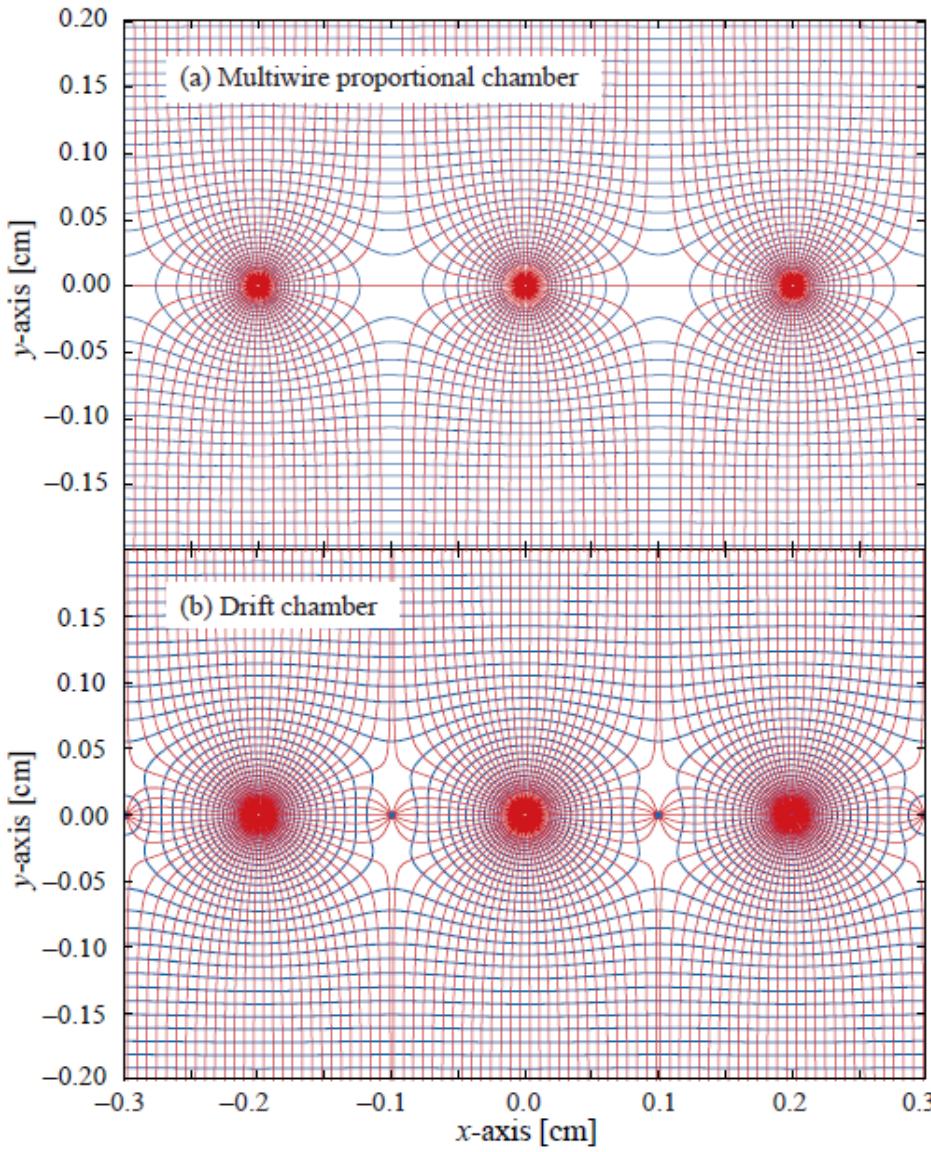
Wire Structure Gaseous Detectors



Various improvements, however:

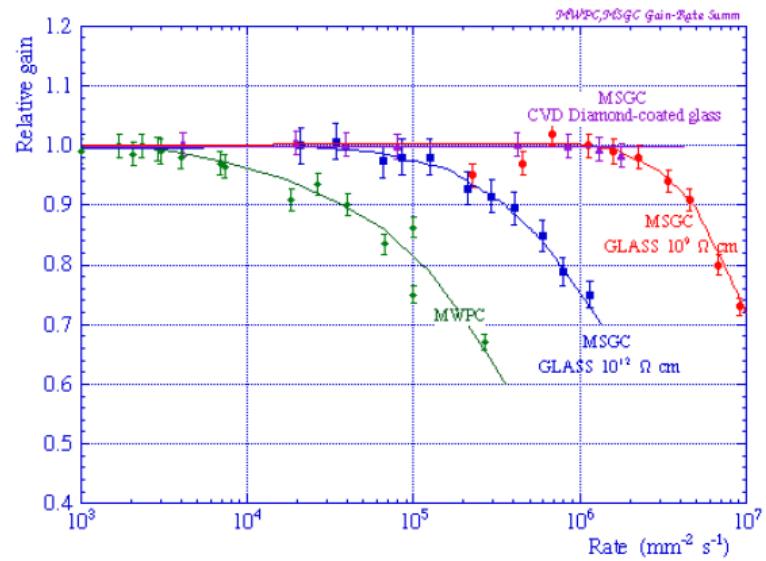
- Basic diffusion processes and space charge effects $\rightarrow \sigma \geq 100 \mu\text{m}$

Wire Structure Gaseous Detectors

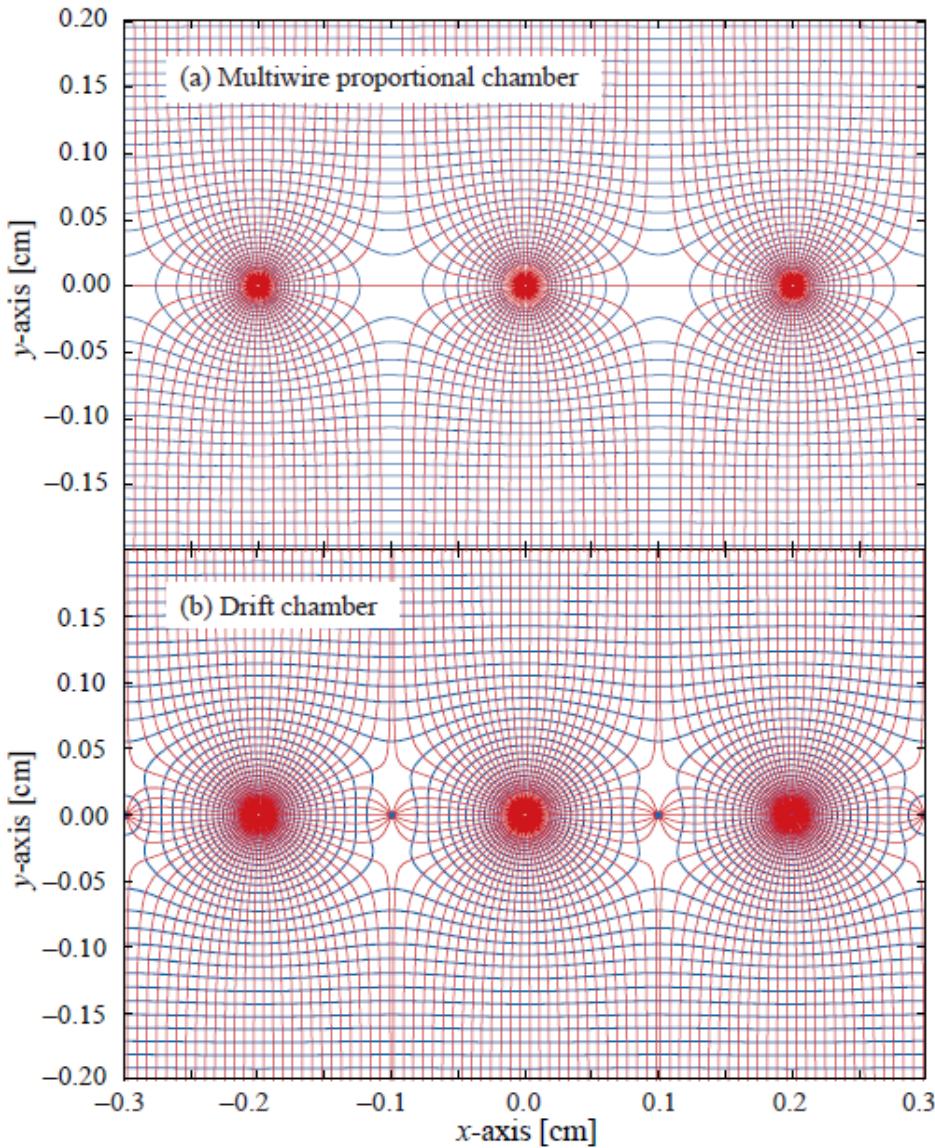


Various improvements, however:

- Basic diffusion processes and space charge effects $\rightarrow \sigma \geq 100 \mu\text{m}$
- Gain of MWPC starts dropping at rate $\geq 10^4 \text{ Hz mm}^{-2}$ \rightarrow loss of detection efficiency



Wire Structure Gaseous Detectors



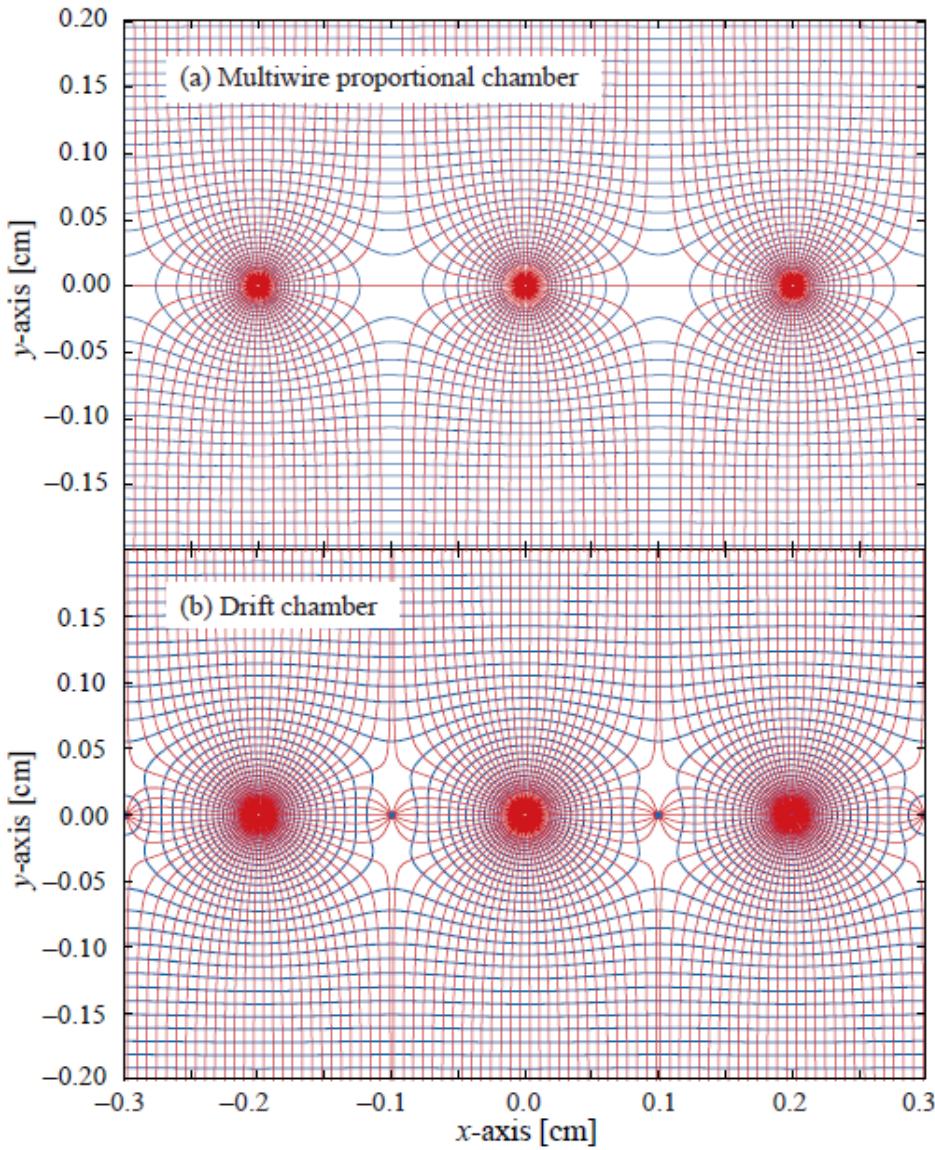
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 - Mechanical difficulties to produce sub-mm wire spacing

Limit with digital readout and wire spacing s :

$$\sigma = \frac{s}{\sqrt{12}}$$

Wire Structure Gaseous Detectors

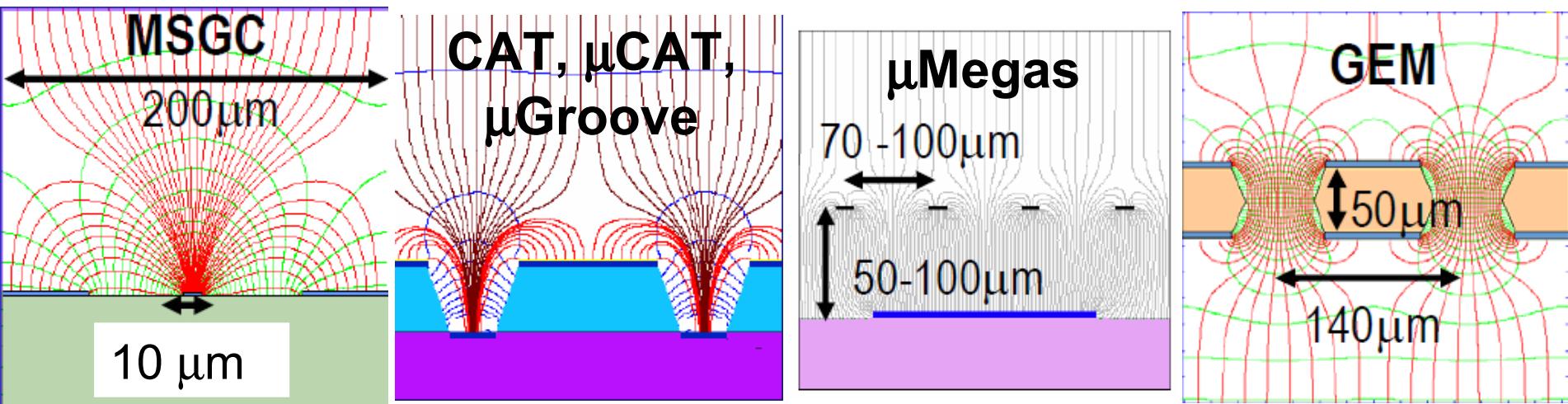


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 - Mechanical difficulties to produce sub-mm wire spacing
 - Ageing concerns

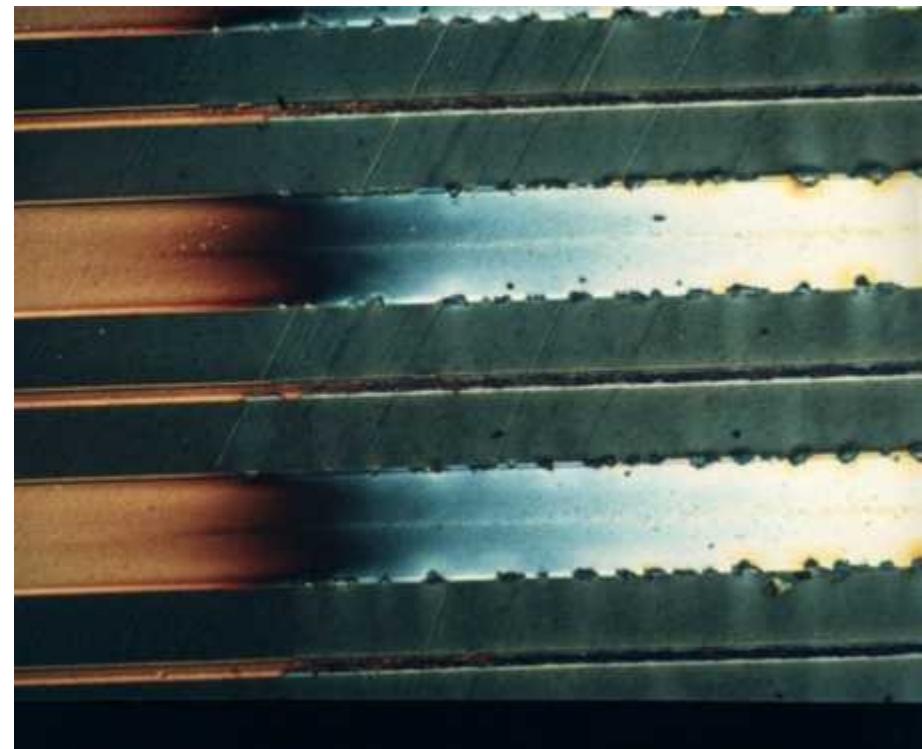
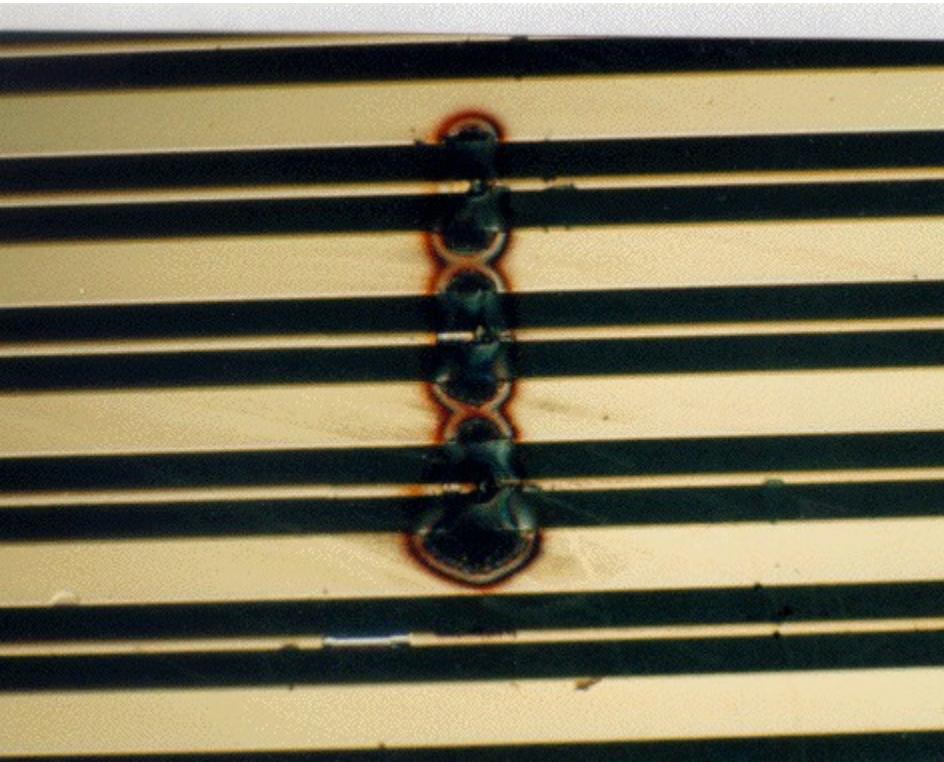
Micro Pattern Gaseous Detectors

- Modern photo-lithographic technology → novel Micro-Pattern Gaseous Detectors (MPGD) concepts are overcoming cell size limitations
- Pitch size a few hundreds of μm
- Intrinsic high rate capability $> 10^5 \text{ Hz/mm}^2$
- Excellent spatial resolution $\sim 30 \mu\text{m}$
- Single photo-electron time resolution in ns-range



Micro Pattern Gaseous Detectors

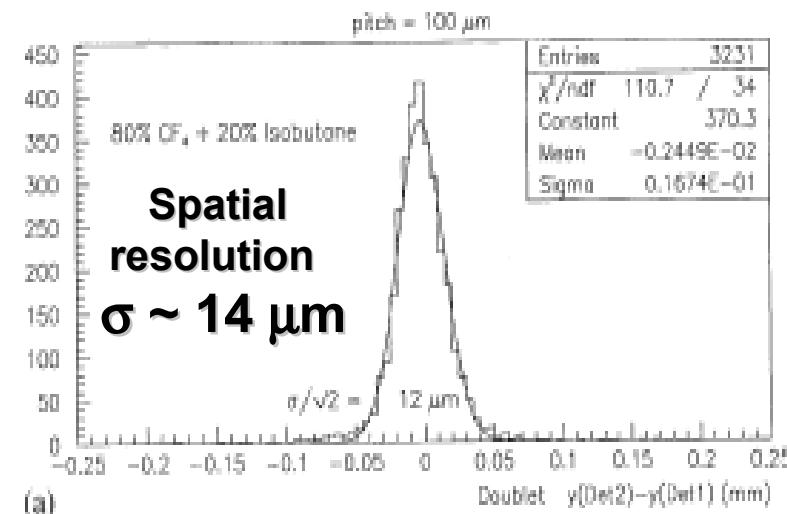
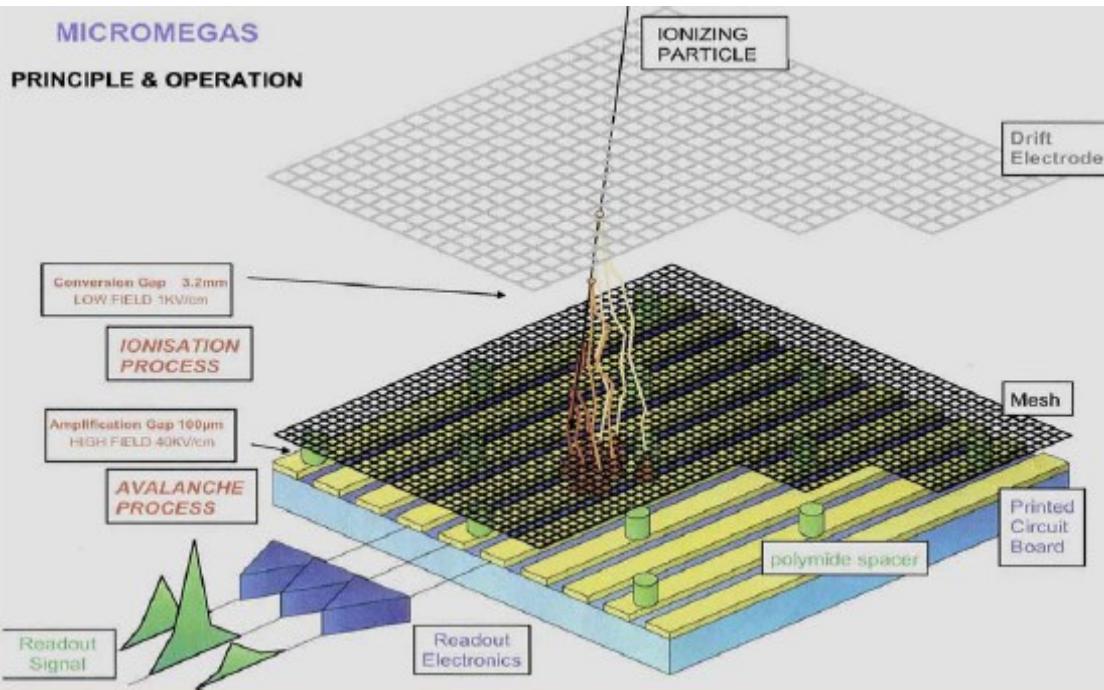
Problem of MSGC: Rare but damaging discharges, and slow but continuous deterioration (aging) during sustained irradiation



Micro Pattern Gaseous Detectors

MicroMesh Gas Structure: Micromegas
Parallel plate multiplication in thin gaps
between a fine mesh and anode plate
Small gap → good energy resolution

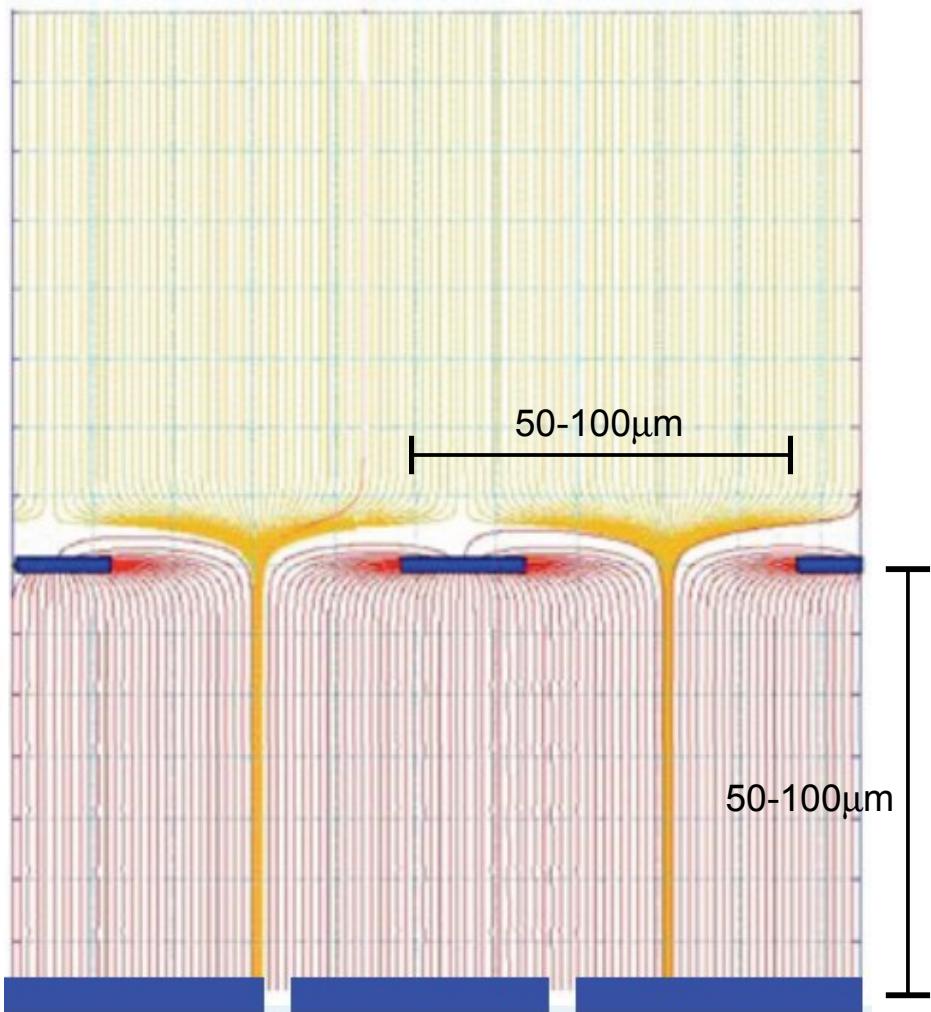
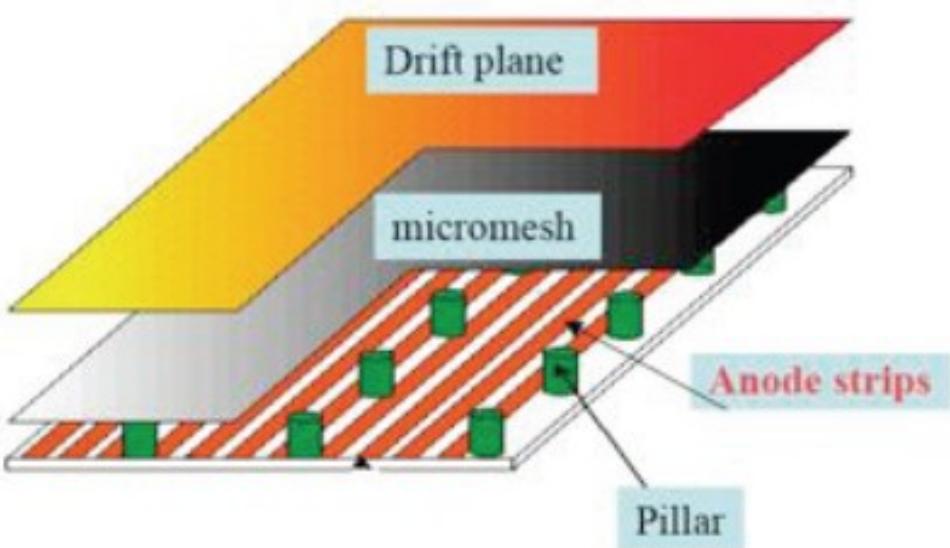
Y. Giomataris,
NIM A376(1996) 29



J. Derre et al, NIM A459 (2001) 523

Micro Pattern Gaseous Detectors

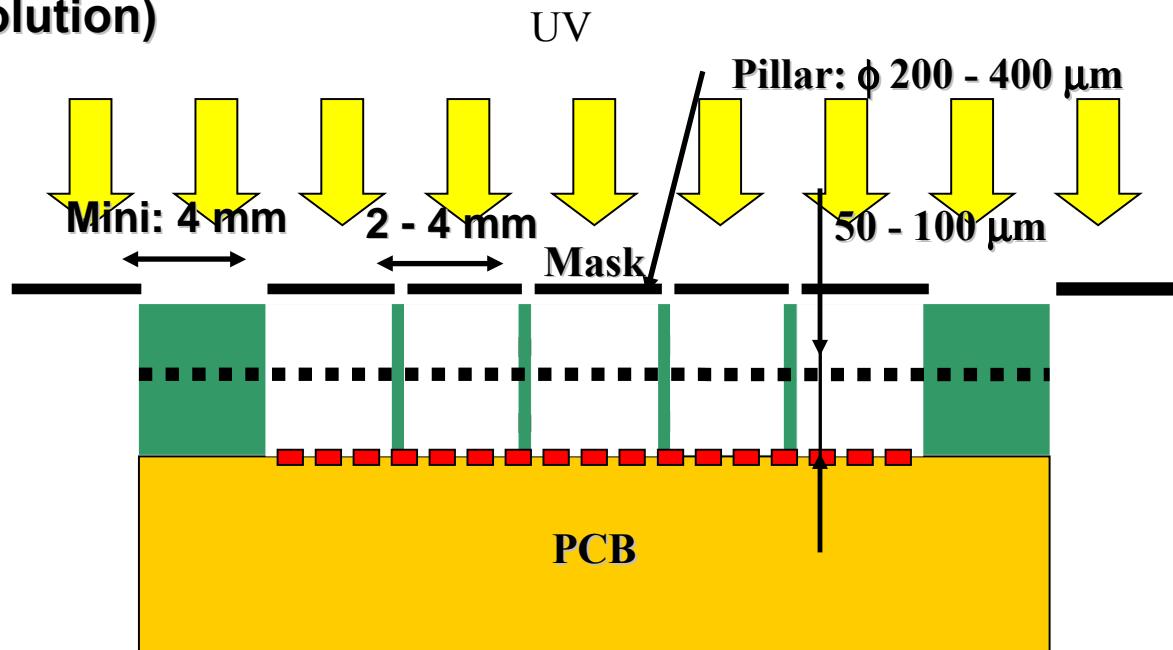
MicroMegas Funnel Effect



Micro Pattern Gaseous Detectors

“Bulk” Micromegas: combined assembly of grid and PCB:

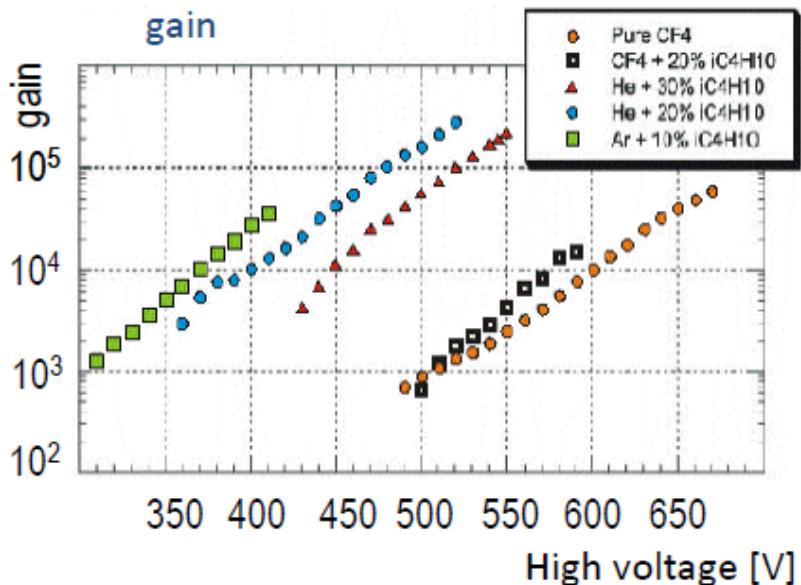
- 1) PCB
- 2) Photoresistive film lamination (50 - 150 μm)
- 3) Mesh lamination (ϕ 19 μm 500 LPI)
- 4) Photoresistive film lamination (50 - 150 μm)
- 5) UV exposure through mask
- 6) Development (chemical solution)



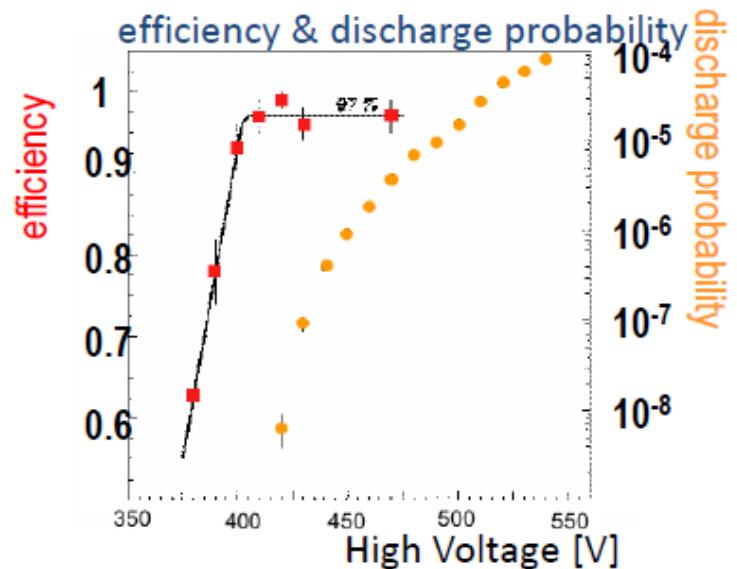
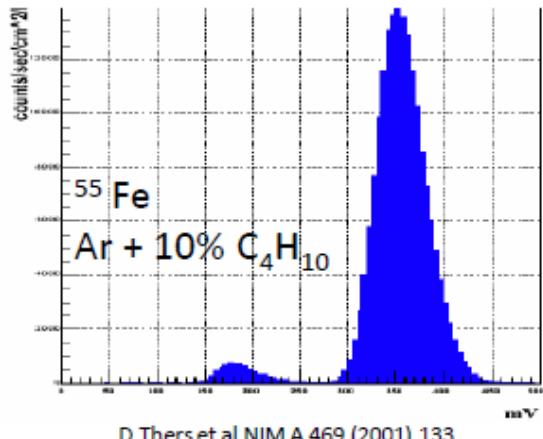
I. Giomataris et al, NIM A560 (2006) 405

Micro Pattern Gaseous Detectors

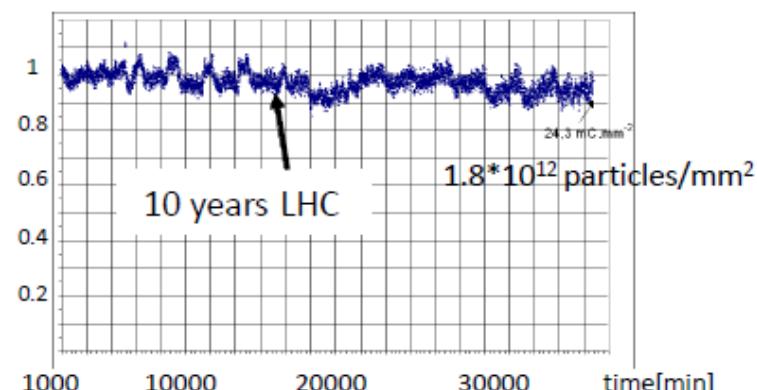
MicroMegas



energy resolution $\sim 10\%$

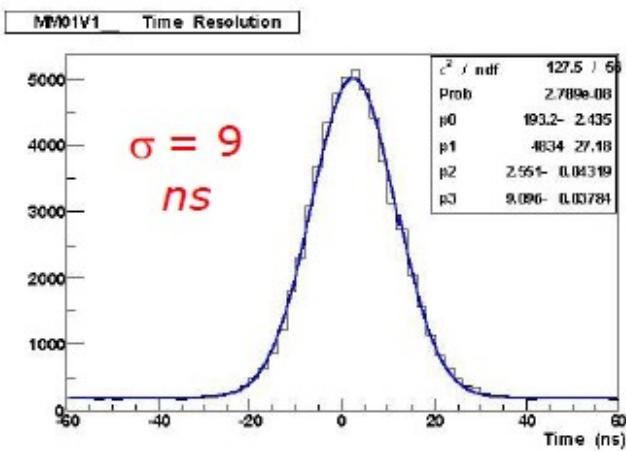
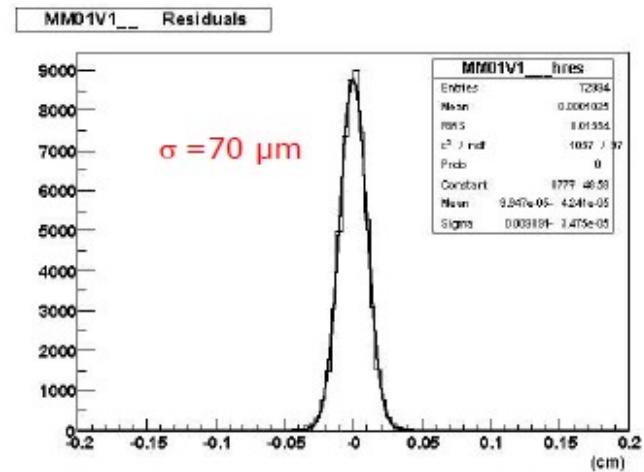
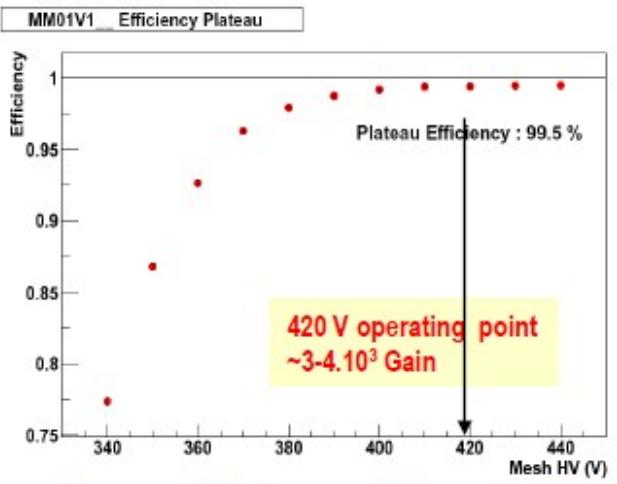


ageing:Ar-iC₄H₁₀ 94-6% up to 24.3mC/mm²

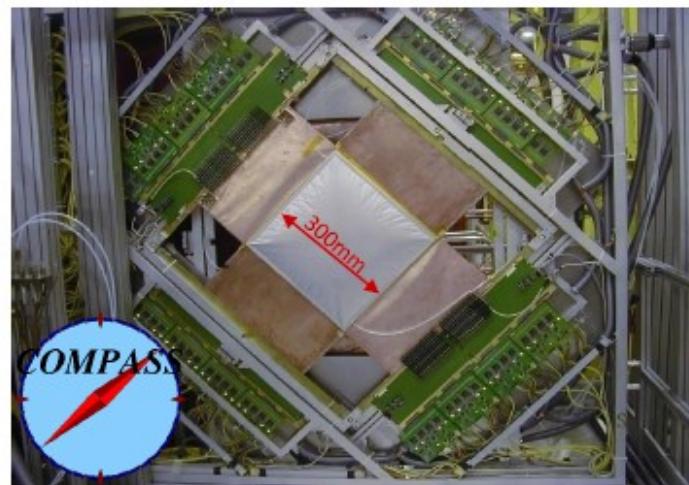


Micro Pattern Gaseous Detectors

MicroMegas



Time resolution : 9 ns

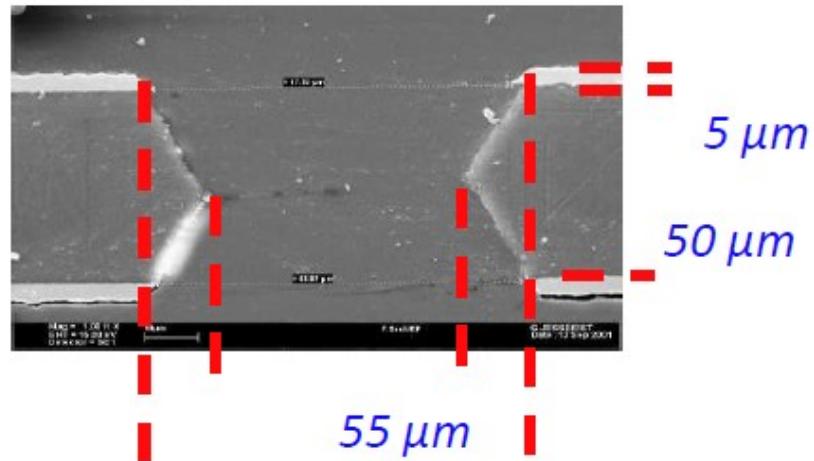
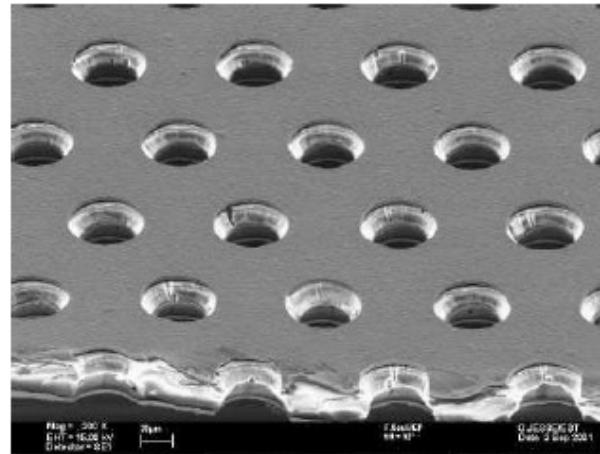
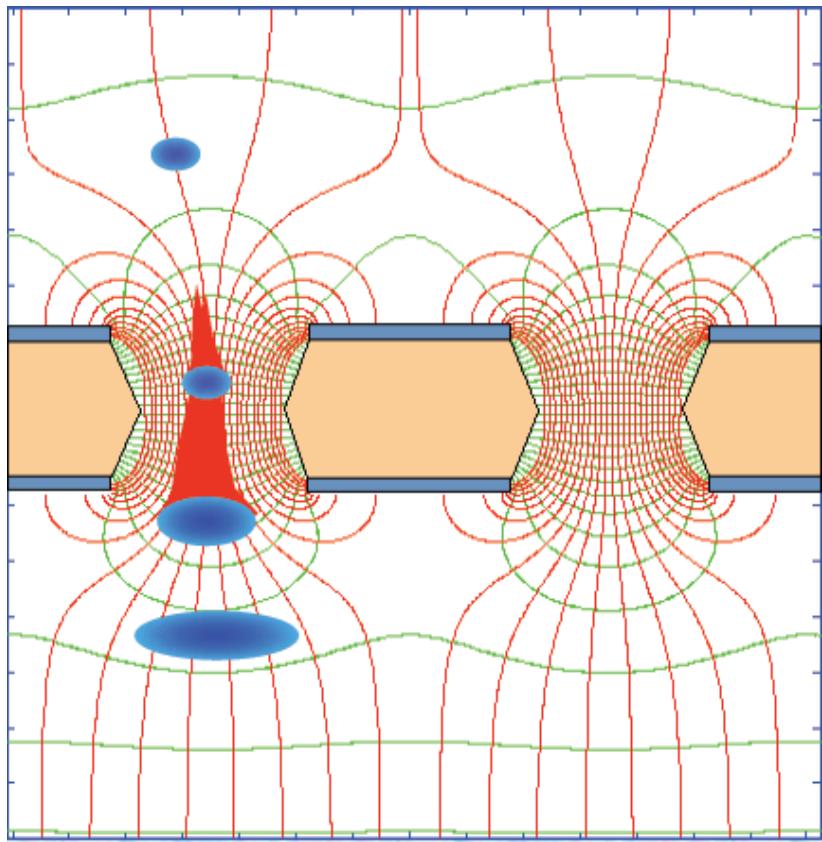


Micro Pattern Gaseous Detectors

Gas Electron Multiplier: **GEM**

F. Sauli, NIM A386(1997) 531

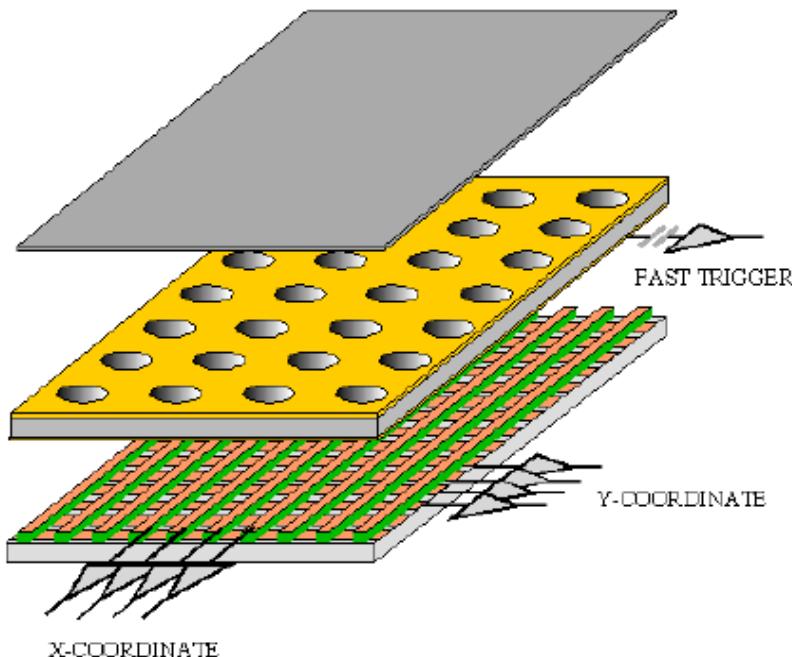
Thin metal coated polyimide foil,
high density hole perforation



55 μm
70 μm

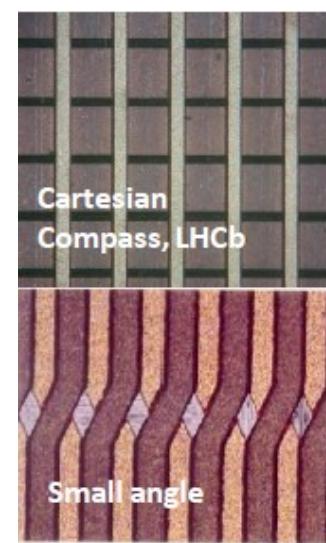
Micro Pattern Gaseous Detectors

GEMs



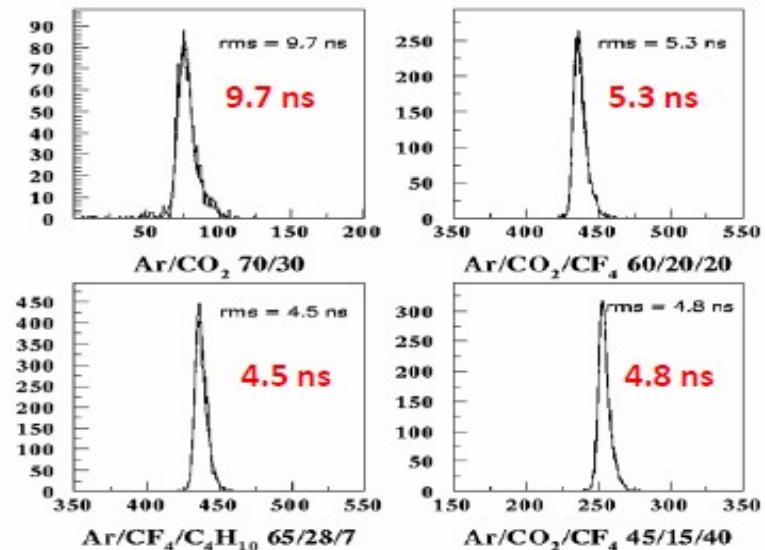
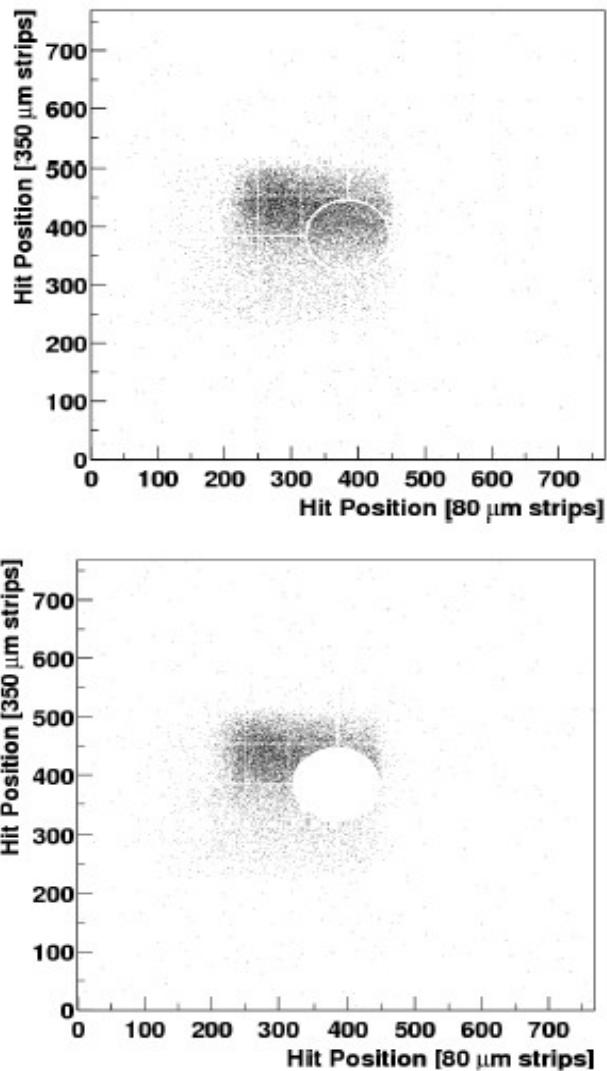
Fully decoupled:
charge amplification and readout
structure

→
both can be individually optimized

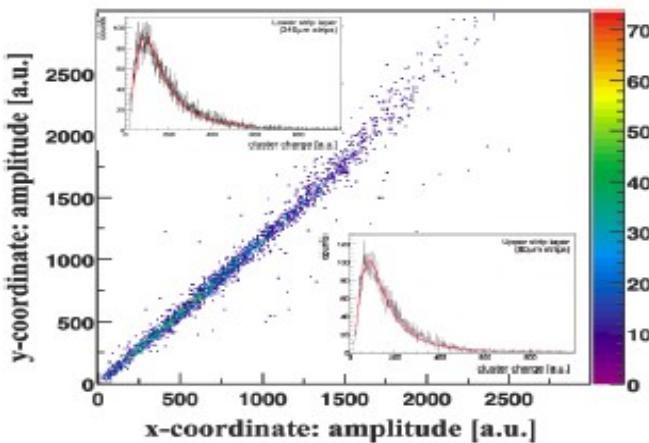


Micro Pattern Gaseous Detectors

GEM



Time resolution

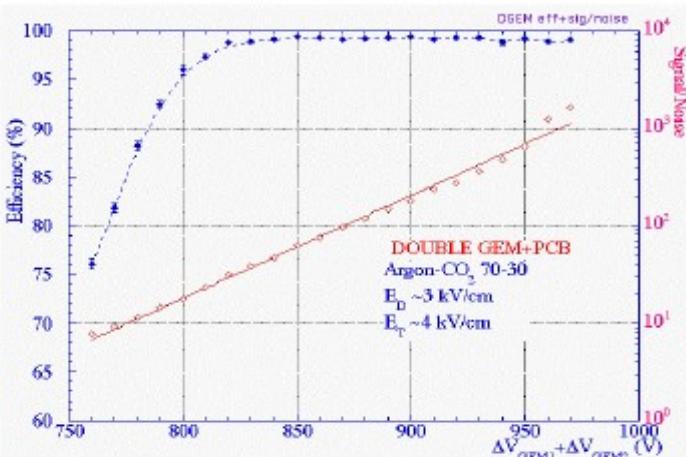


Charge correlation (Cartesian readout)

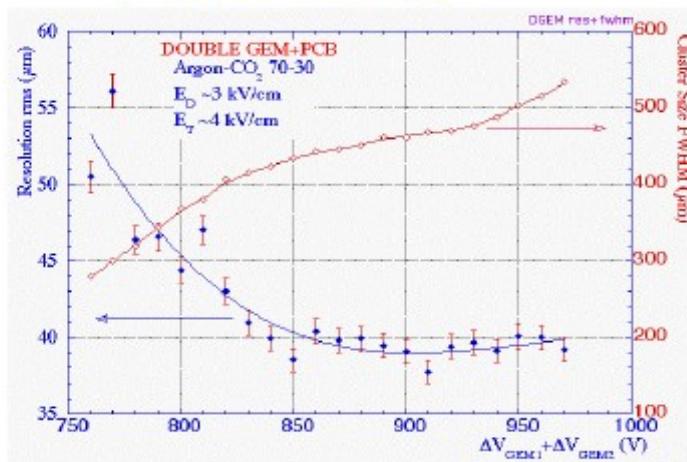
Micro Pattern Gaseous Detectors

GEM

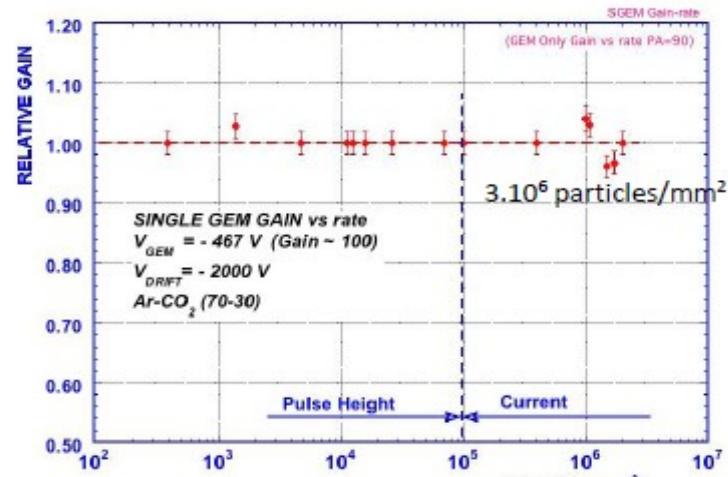
A. Bressan et al, Nucl. Instr. And Meth. A425(1999)262



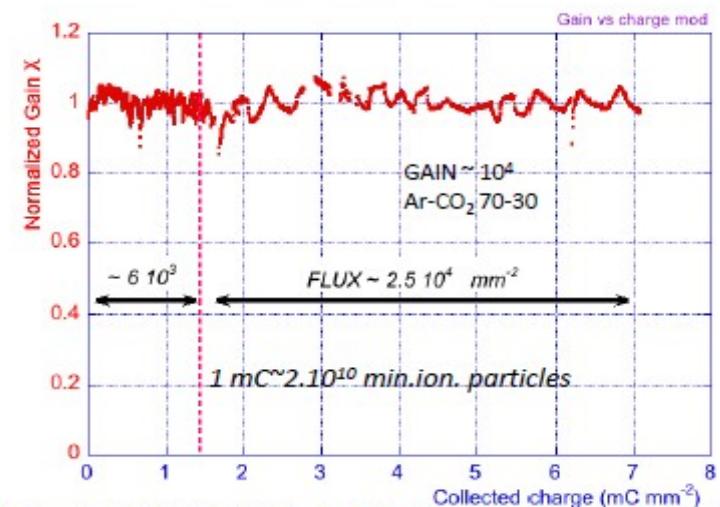
Efficiency for minimum ionizing
particles with 3 mm gap



Space resolution $\sim 40 \mu\text{m}$ rms
Cluster size $\sim 500 \mu\text{m}$ FWHM



Rate capability $> 10^6 \text{ Hz mm}^{-2}$

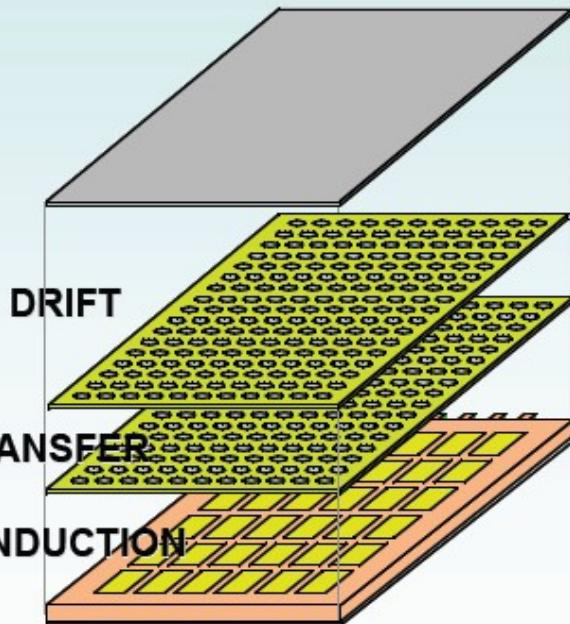


C. Altunbas et al, DESY Aging Workshop (Nov. 2001) Nucl. Instr. and Meth. A
J. Benloch et al, IEEE NS-45(1998)234

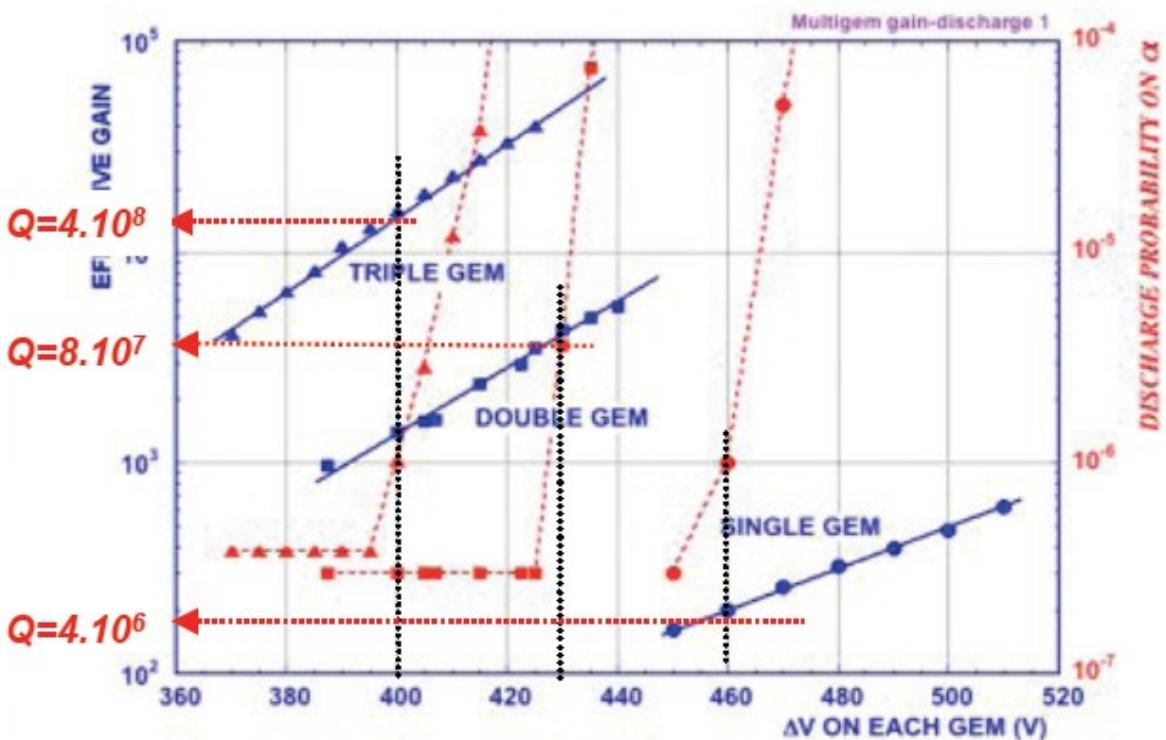
Micro Pattern Gaseous Detectors

Cascading several GEMs reduces the voltage needed on each foil for the same gain, and largely increases the maximum gain

F. Sauli



$^{241}\text{Am } \alpha$ particles $\sim 2.10^4$ e- l^+ pairs



S. Bachmann et al, Nucl. Instr. and Meth. A479(2002)294

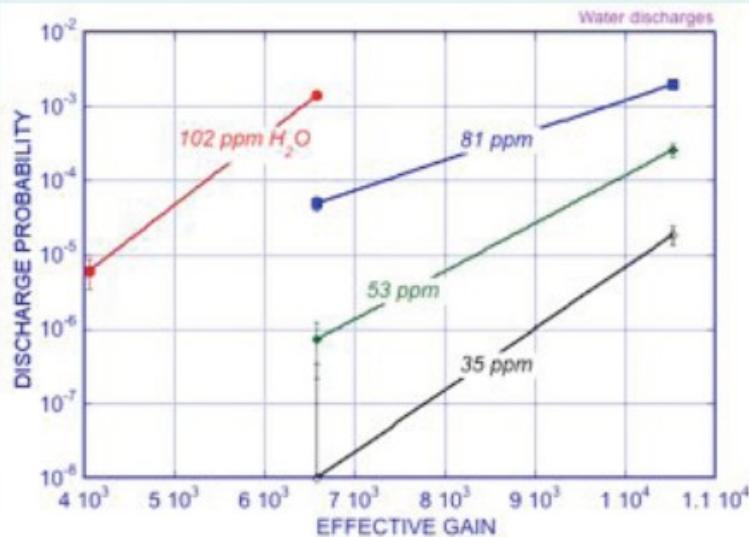
Micro Pattern Gaseous Detectors

F. Sauli

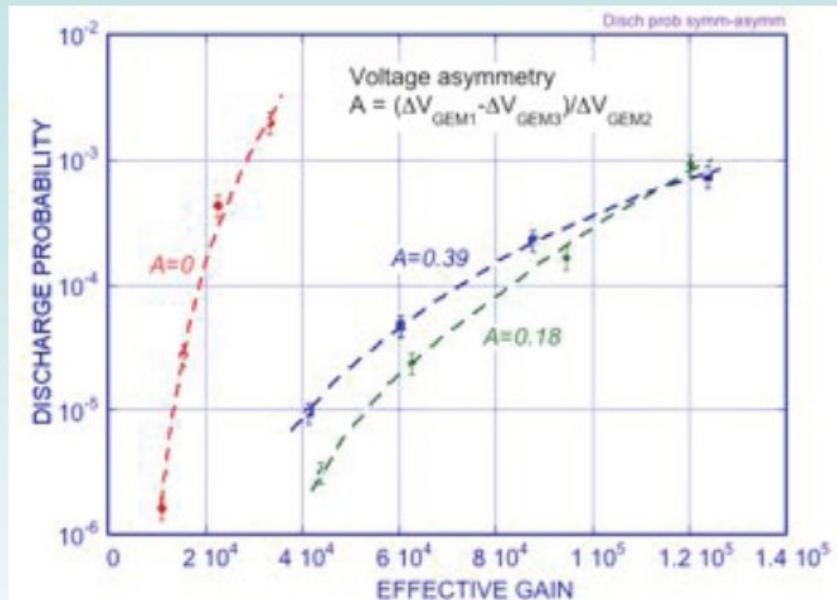
Possible explanations:

- the additional avalanche spread due to diffusion decreases the charge density in each hole
- to get the same gain in cascaded electrodes, each foil operates at a voltage much below the natural discharge point.

For the same total gain, the discharge probability is much smaller with asymmetric voltage distribution (the first GEM in the cascade having higher voltage than the last), probably a demonstration of the voltage dependence of the Raether limit.



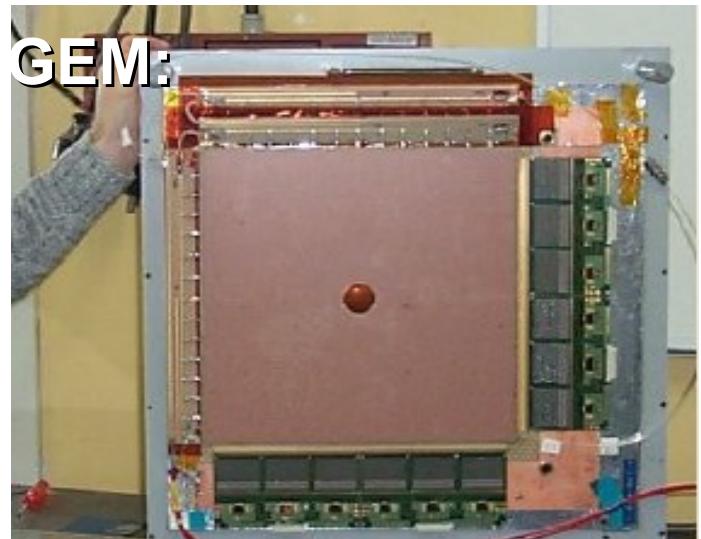
TRIPLE GEM: DISCHARGE PROBABILITY VS VOLTAGE ASYMMETRY



C. Altumbas et al, Nucl. Instr. and Meth. A490(2002)177

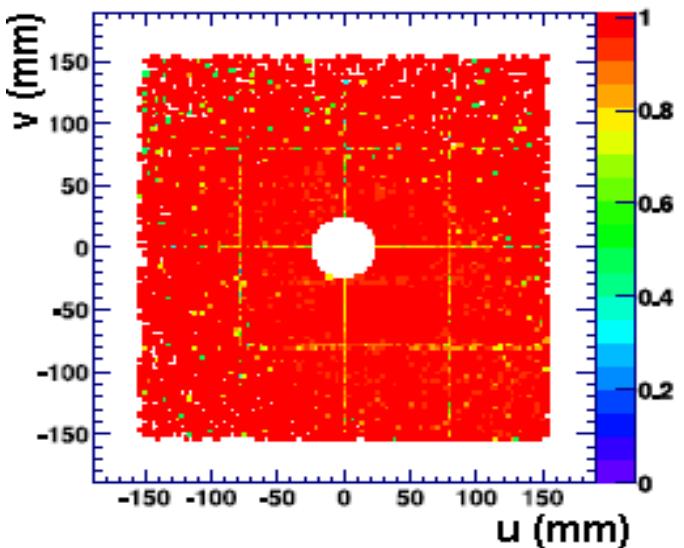
EFFECT OF WATER CONTENT ON DISCHARGE PROBABILITY

Micro Pattern Gaseous Detectors



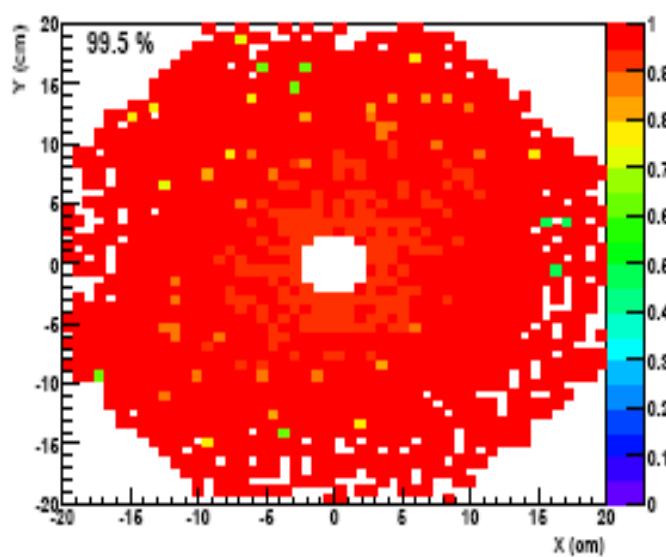
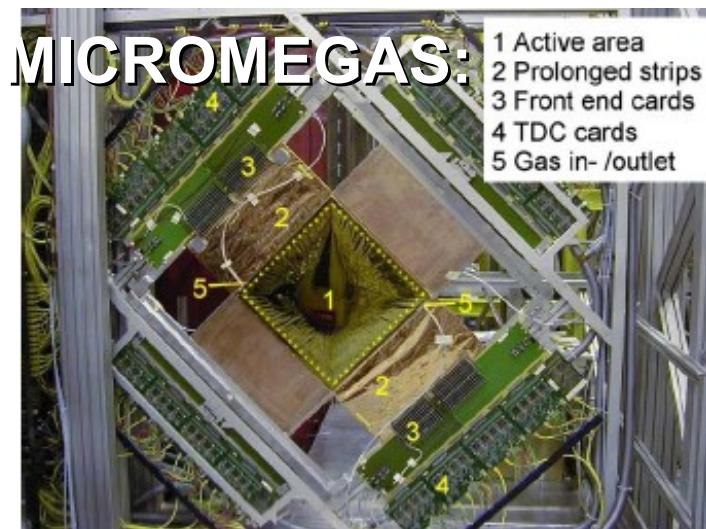
**RELIABLE
OPERATION
from 2002**

**NO SIGN
OF AGING**



**TRACKING
EFFICIENCY
uniform:**

($\varepsilon > 95\%$)

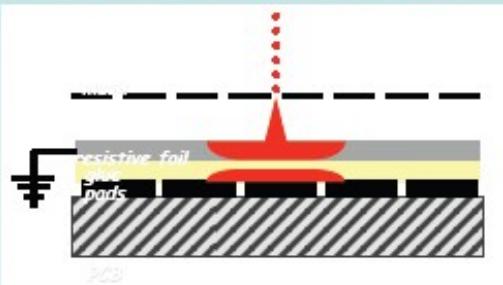


Micro Pattern Gaseous Detectors

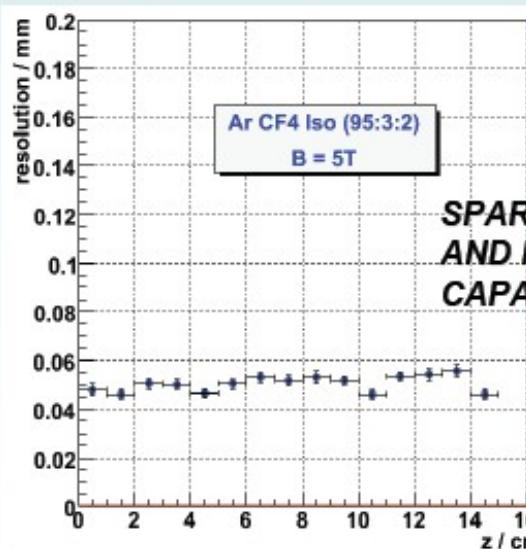
F. Sauli

MPGD WITH RESISTIVE ELECTRODES

RESISTIVE ANODE: CHARGE DISPERSION READOUT



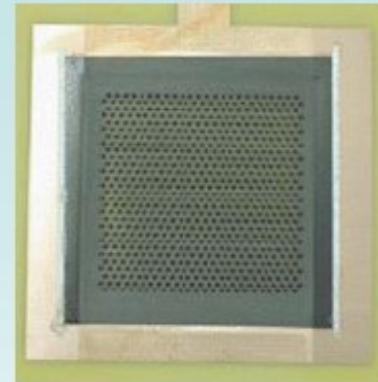
EXCELLENT POSITION ACCURACY:



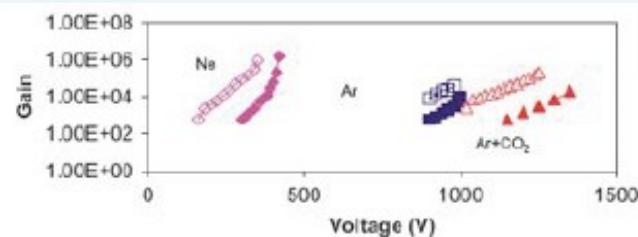
SPARK PROTECTION AND RATE CAPABILITY?

RTGEM: RESISTIVE ELECTRODE THICK GEM

$3\text{--}10 \text{ G}\Omega/\square$ copper oxide layer



GAIN OF RETGEM IN VARIOUS GASES:



A. Di Mauro et al, Nucl. Instr. and Meth. A581(2007)225

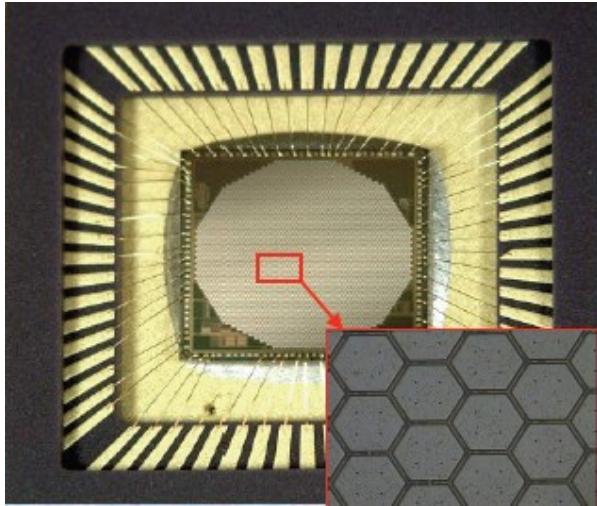
M. Dixit et. al, Nucl. Instr. and Meth. A581, 254 (2007)

MPGD Readout

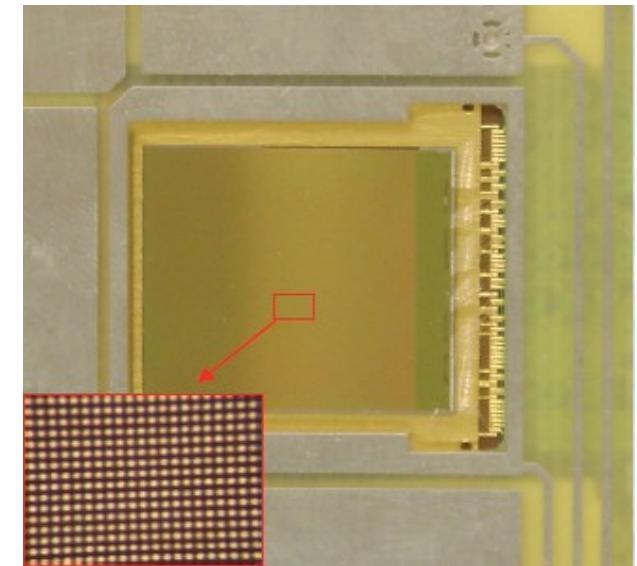
Gas Detector readout by means of multi pixel CMOS array:

Integrating detector and electronics

High rate particle tracking w/o ambiguity of multi-track/-hit events



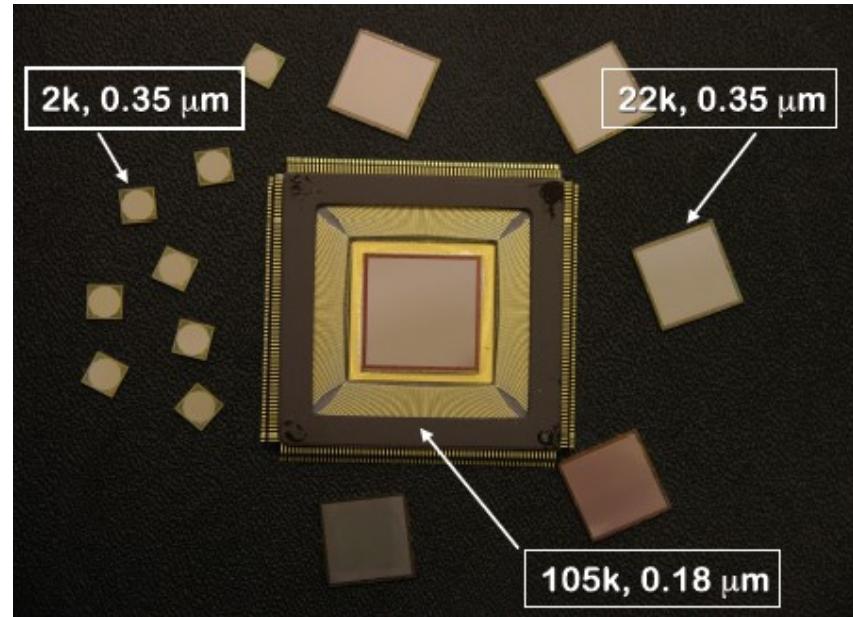
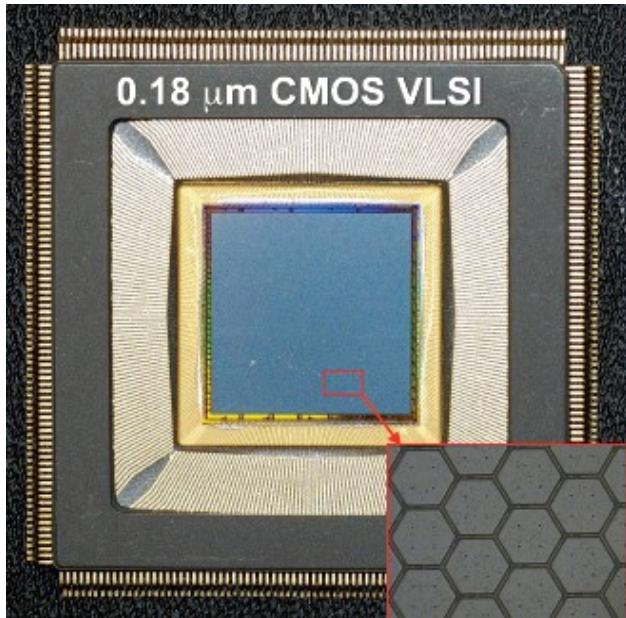
VLSI ASIC (PISA)



MediPix/TimePix
CMOS chip

MPGD Readout

GEM and Very Large Scale Integration VLSI



Six layers 0.18 μm CMOS technology with
self-triggering capability

50 \times 50 μm pixels with 470 pixels/ mm^2

Serial analog readout for each pixel

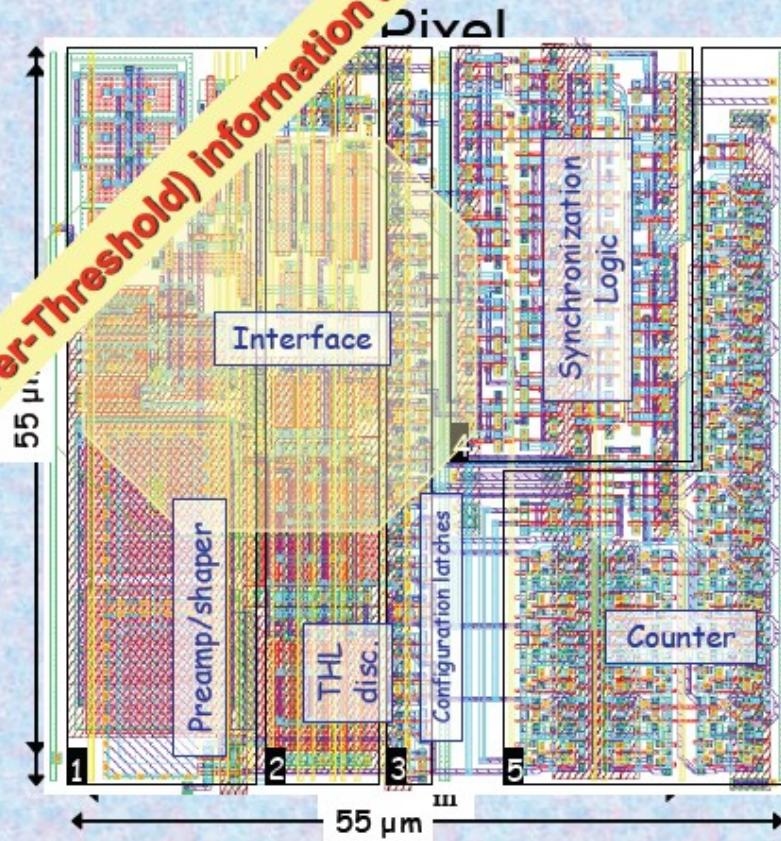
Noise ENC \sim 50 e⁻ per channel

E .Costa et al., Nature 411 (2001) 662
R. Bellazzini et al., NIMA535 (2004) 477
R. Bellazzini et al., NIMA560 (2006) 425
R. Bellazzini et al., NIMA566 (2006) 552

MPGD Readout

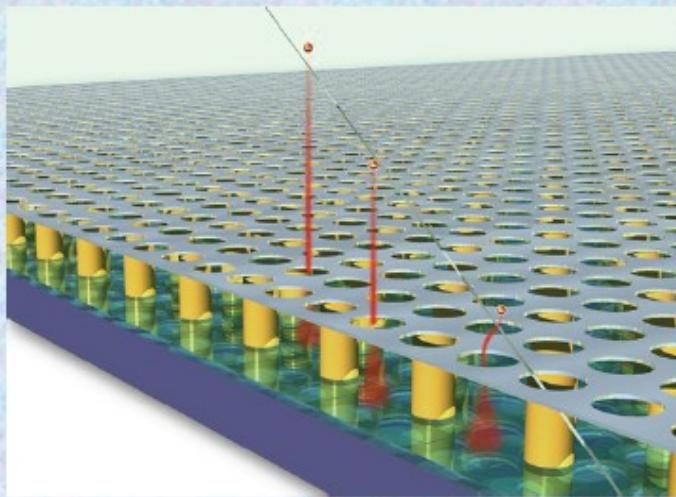
Medipix / Timepix CMOS Chip

- Chip (CMOS ASIC) upgraded in the EUDET framework for high energy physics from the Medipix2 chip developed first for medical applications
 - IBM technology 0.25 μm on 6 layers
 - Characteristics:
 - surface: 1.4 x 1.6 cm^2
 - matrix of 256 x 256
 - pixel size: 55 x 55 μm^2
 - For each pixel:
 - preamp/shaper
 - threshold discriminator
 - register for configuration
 - TimePix synchronization logic
 - 14-bit counter
 - Noise: ~ 65 e⁻/pixel, $C_{\text{in}} \sim 15 \text{ fF}$
- Both TIME and Amplitude (Time-Over-Threshold) information are available**

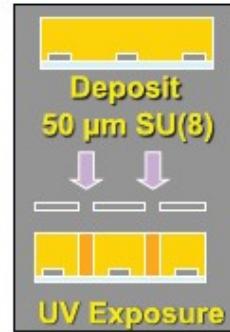


MPGD Readout

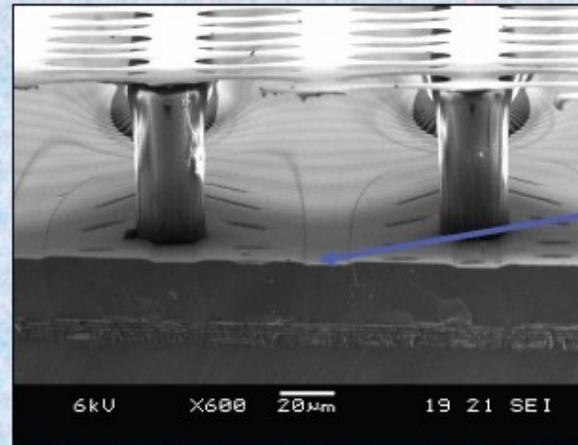
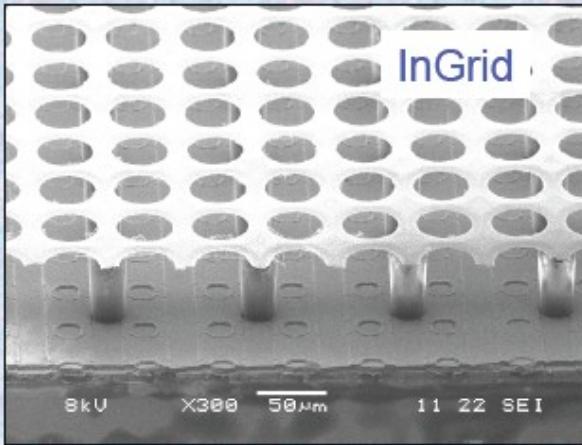
Micromegas/Ingrid + Timepix Detectors



InGrid: integrate Micromegas & pixel chip by Si-wafer post-processing technology
• Grid robustness & Gap/Hole accuracy



Micromegas/Ingrid + SiProt + Timepix Detector:

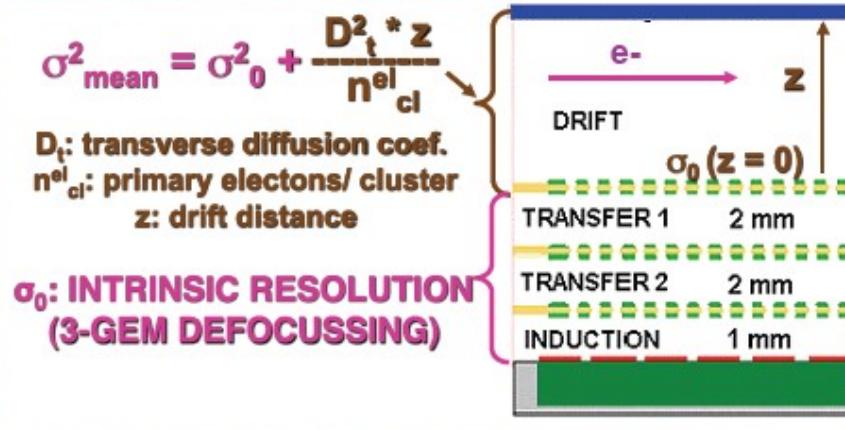


Deposit SiProt layer (3-20 mm of amorphous Si or Si-nitride)

to protect pixel chip against gas discharges

MPGD Readout

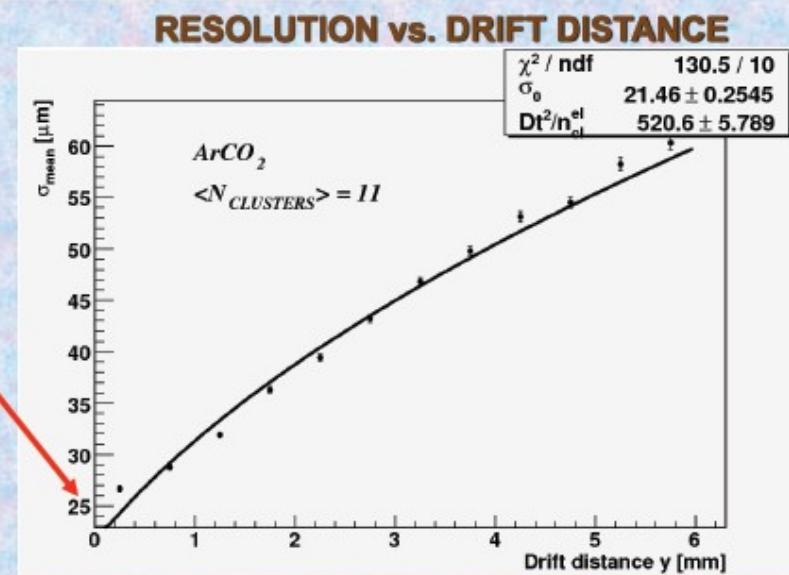
Triple GEM and Timepix: Spatial Resolution



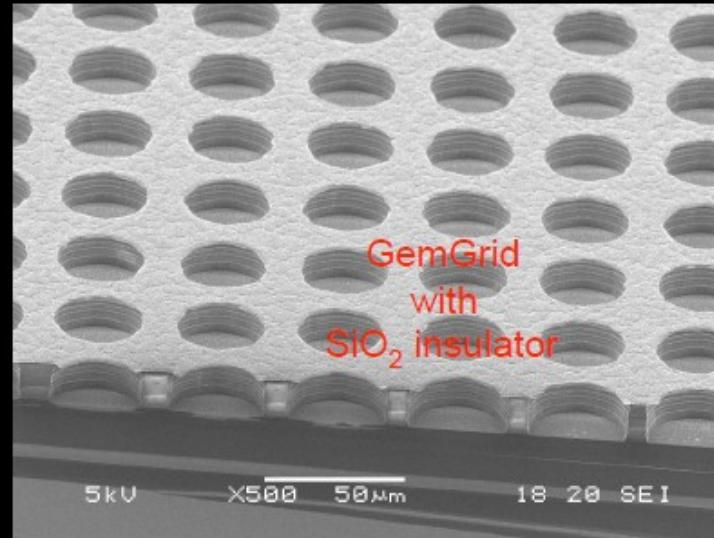
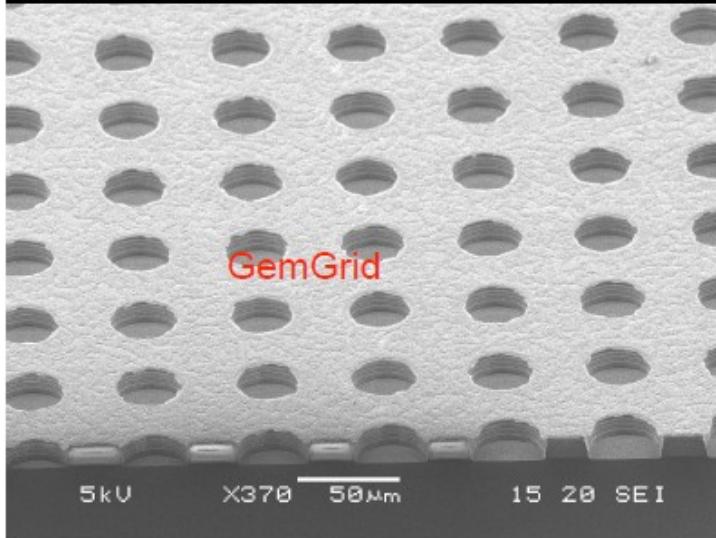
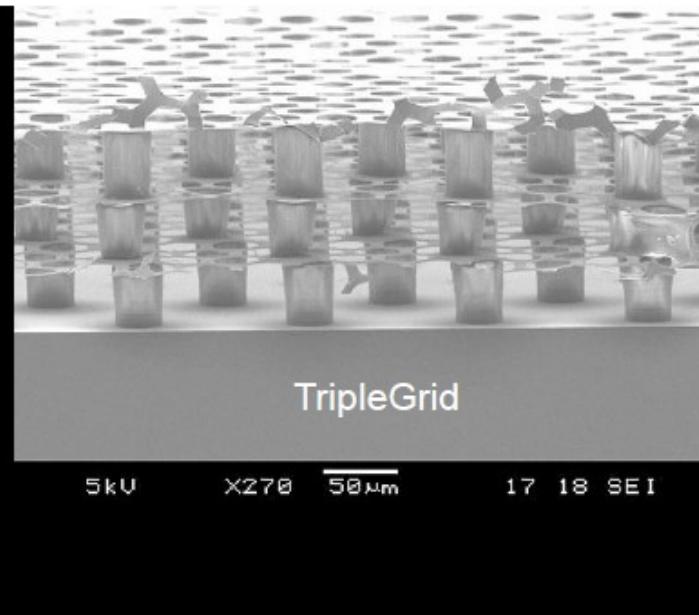
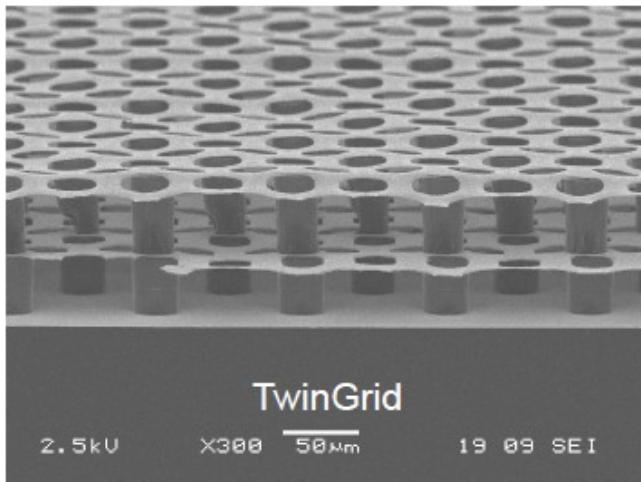
Single point resolution (σ_0)
 at 5 GeV e⁻-beam:

$$\sigma_0 \sim 25 - 30 \mu\text{m}$$

σ_0 → Deviations of "center of gravity"
 of individual cluster avalanches
 from the straight line track
 (dominated by GEM pitch (140 μm))



MPGD Readout



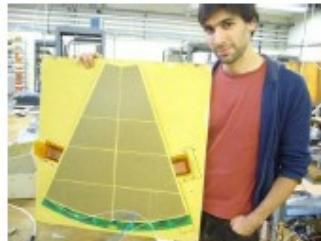
Possible Applications

Large area detector development

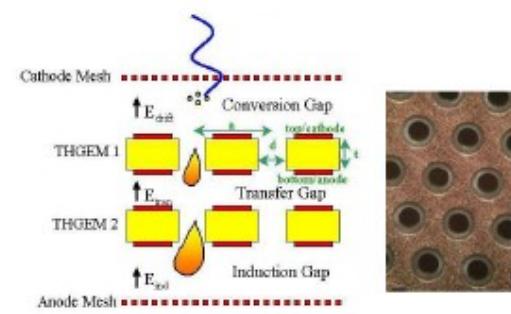
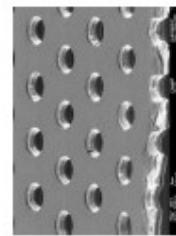
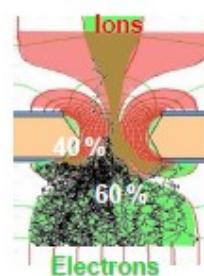
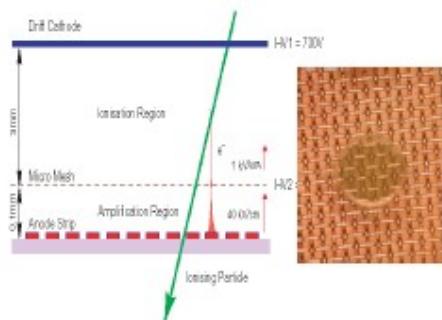
Bulk Micromegas



Single mask GEM

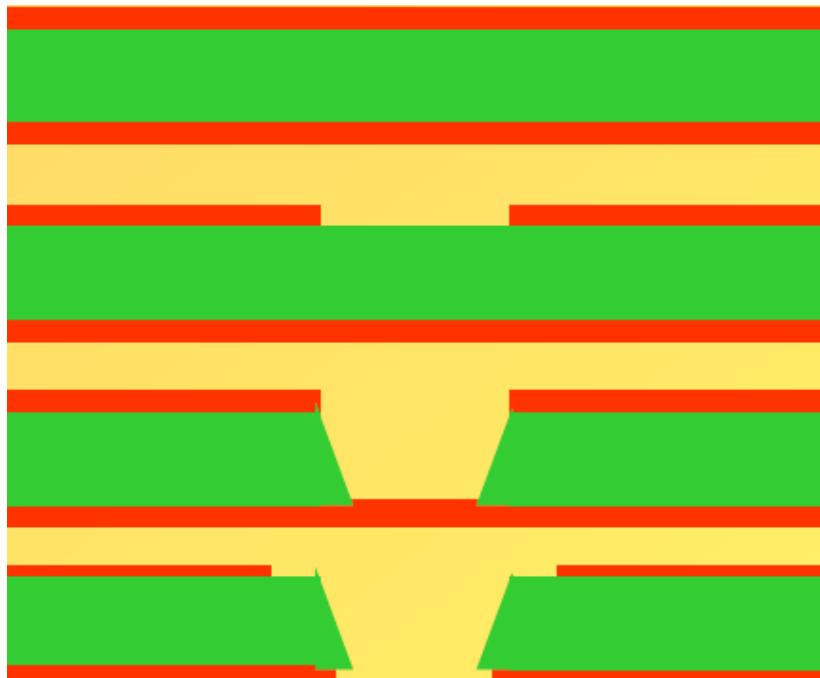


THGEM



Possible Applications

Overcome mask alignment problem



Raw material

Single side Cu pattern

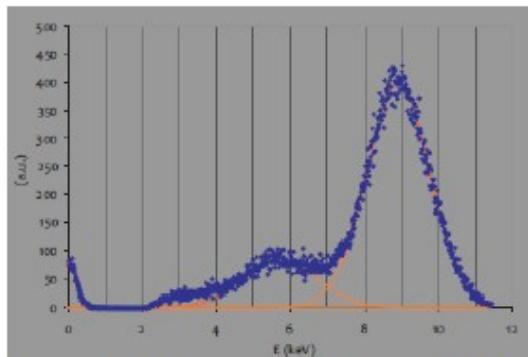
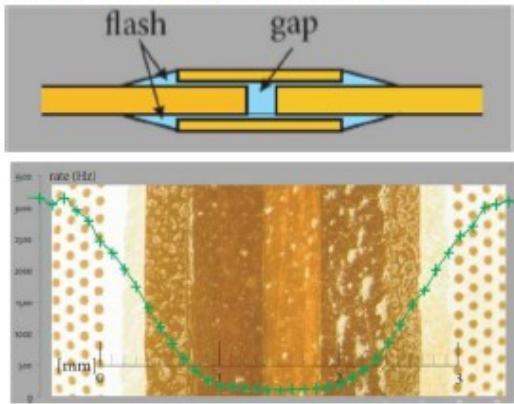
Chemical polyimide etching

Chemical Cu reduction

Possible Applications

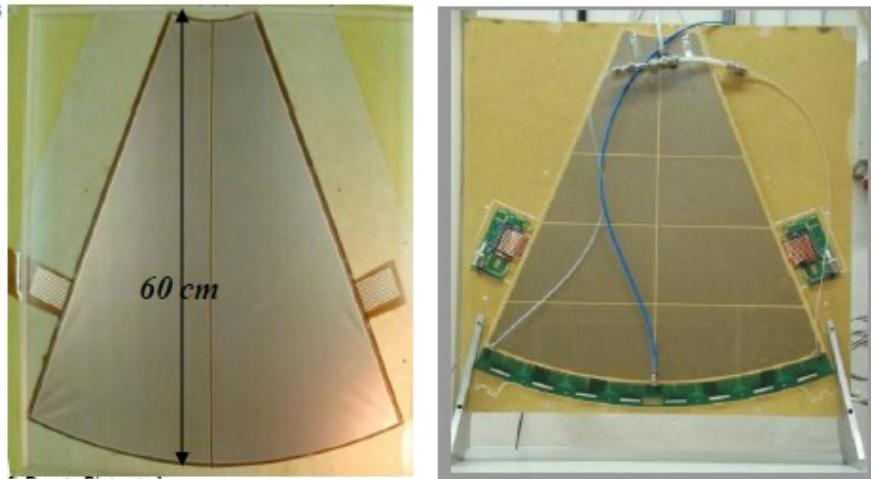
Single mask GEM: splicing

The limit in width (~45 cm) due to the available material is overcome “splicing” together two foils with a ~3 mm wide local efficiency loss

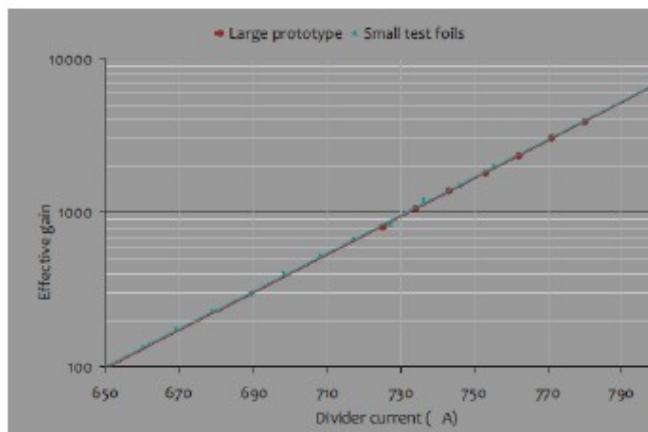


Energy Resolution $\sim 9.5\% (\sigma)$ at 8.9 keV

TWO-SECTORS TRIPLE-GEM PROTOTYPE FOR TOTEM T1
UPGRADE (60x60 cm²)

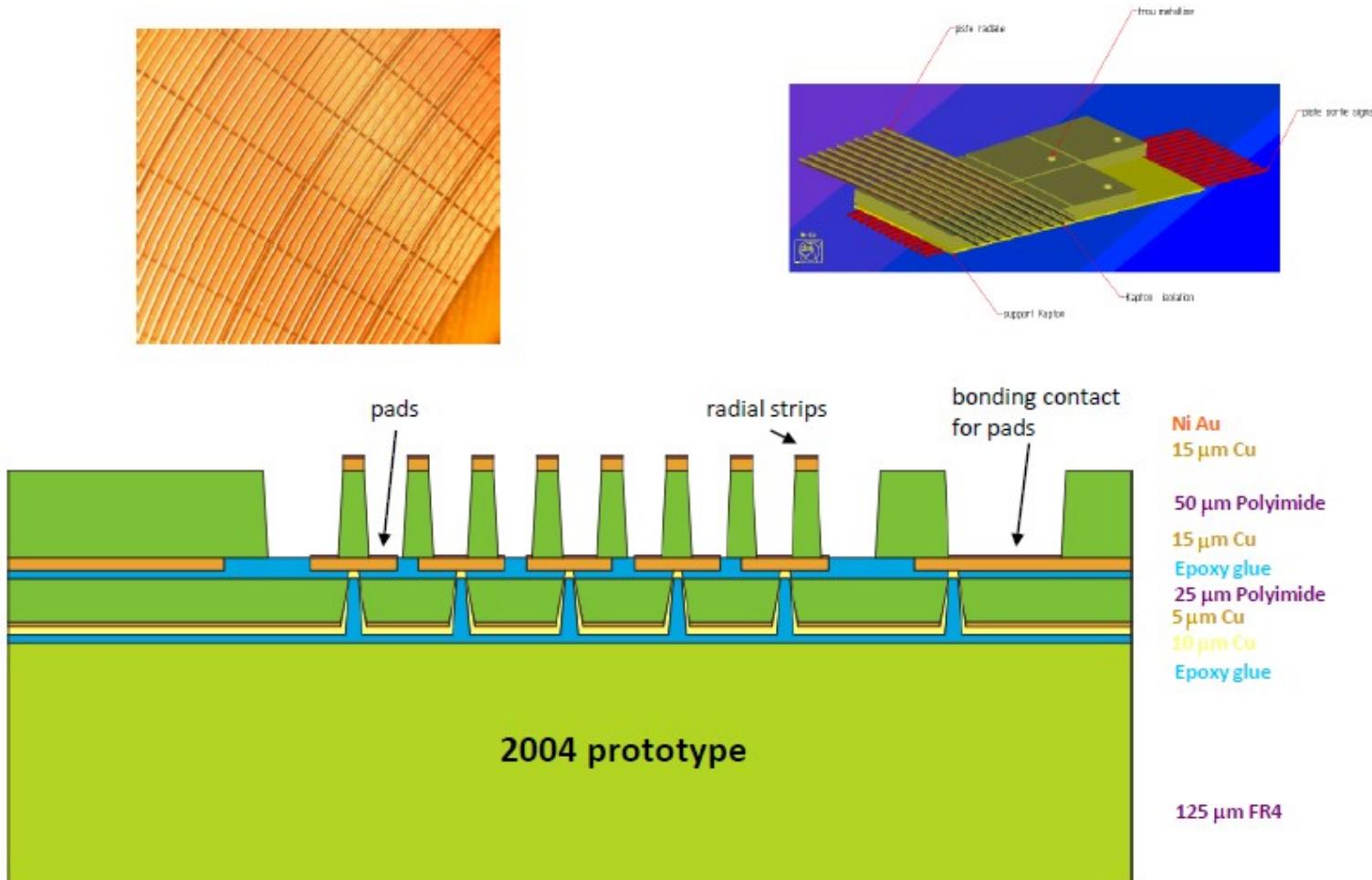


S. Duarte Pinto et al,
IEEE Nucl. Sci. Symp. Conf. Rec. (Dresden, Oct. 2008)



Possible Applications

TOTEM Readout: mixed pad/strip RO-board

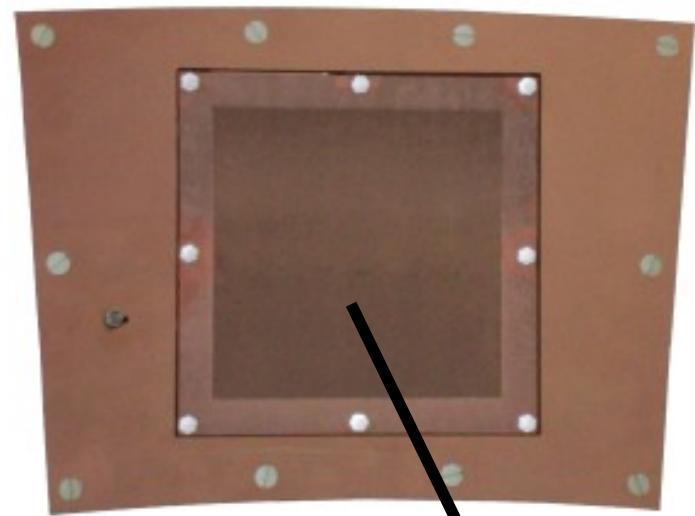


Possible Applications

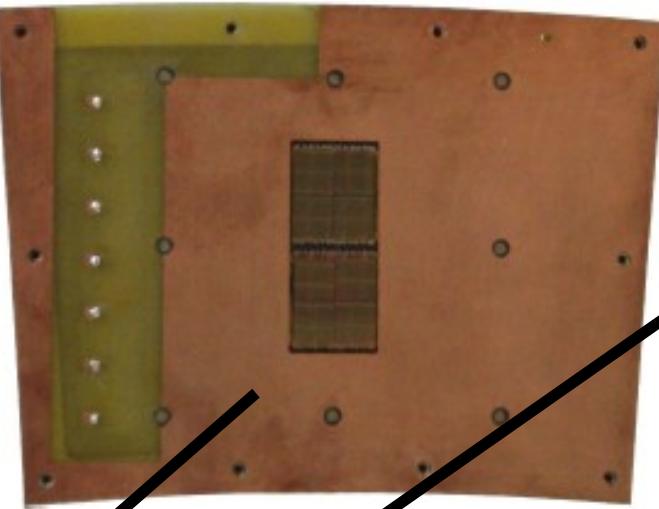
Within RD51

Detector Technology	Currently produced cm * cm	Future Requirements cm * cm
GEM	40 * 40	50 * 50
GEM, single mask	70 * 40	200 * 50
THGEM	70 * 50	200 * 100
RTHGEM, serial graphics	20 * 10	100 * 50
RTHGEM, Kapton	50 * 50	200 * 100
Micromegas, bulk	150 * 50	200 * 100
Micromegas, microbulk	10 * 10	30 * 30

Possible Applications



anode plane



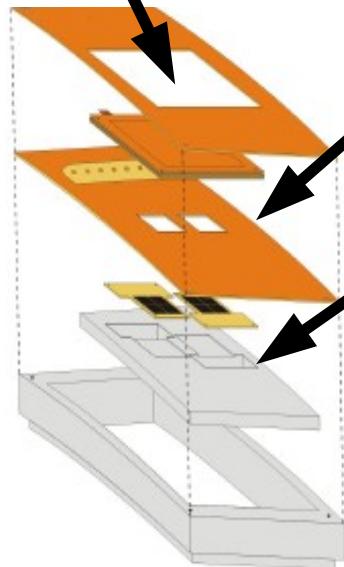
GEMs

readout plane

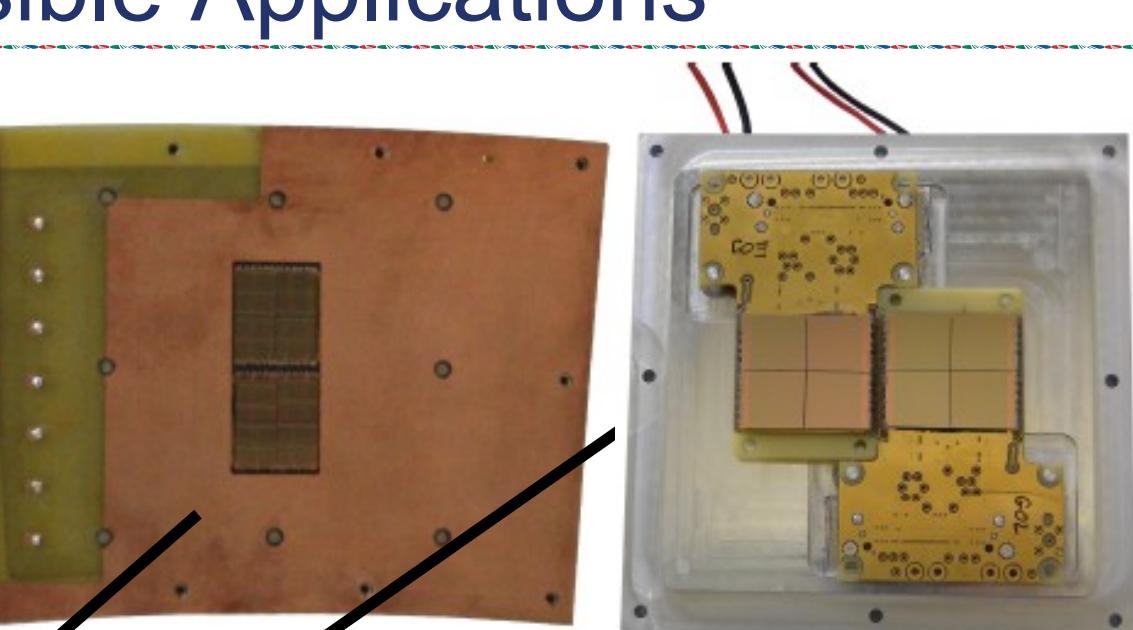
quad-boards

reinforcement of
anode plane

redframe



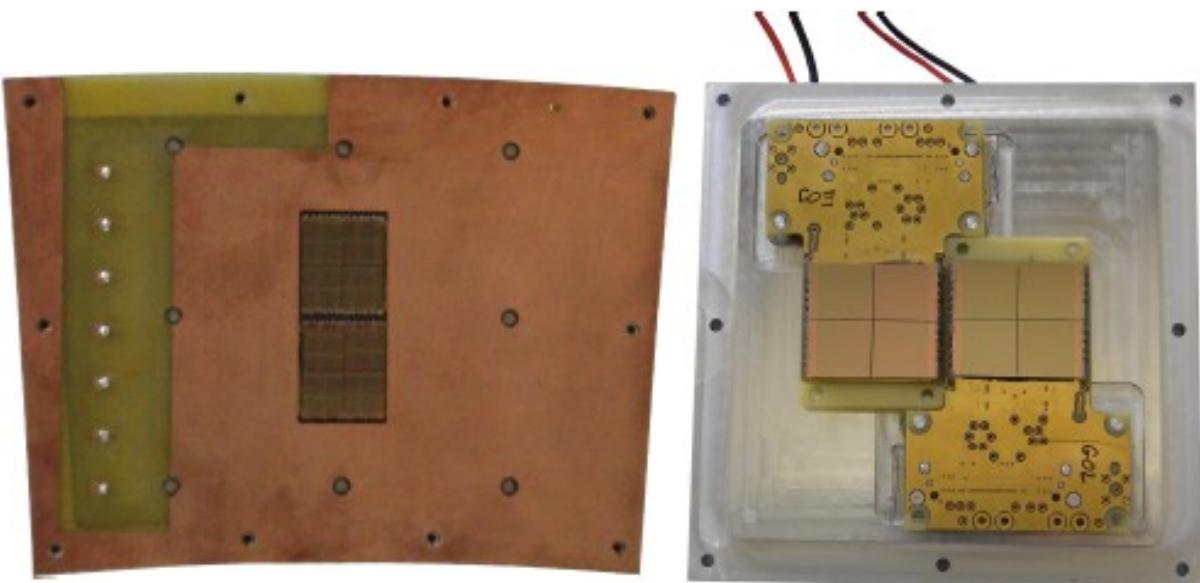
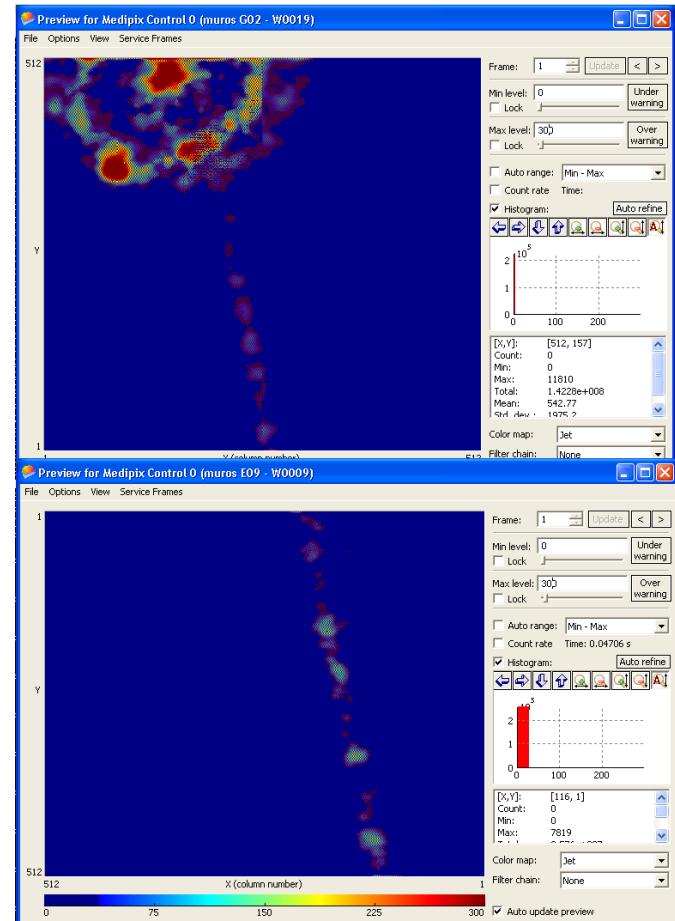
J. Kaminski, Univ. of Bonn



Readout:
2 quadboards
(4 TimePix
Chips each)

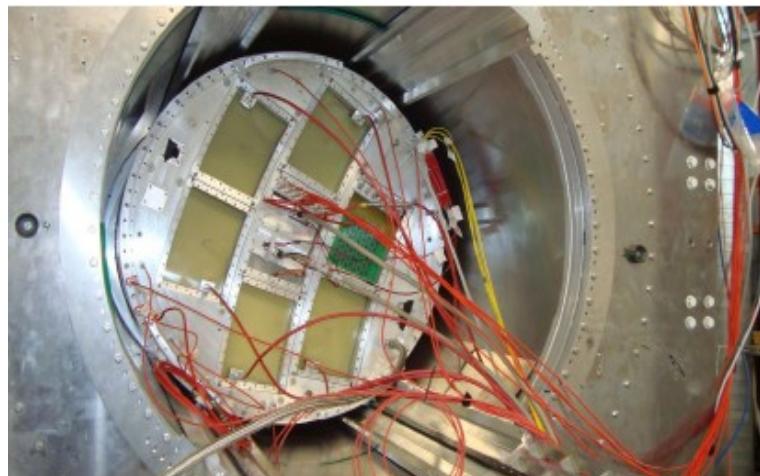


Possible Applications



Readout:
2 quadboards
(4 TimePix
Chips each)

J. Kaminski, Univ. of Bonn



Possible Applications

- PHENIX detector evolution upgrades with GEM-layers
 - Possible additions to central tracking system between VTX and DC
 - Replacement of existing wire chambers
 - Cylindrical GEM electrodes ?
 - rather large radii
 - HBD type modules ?
 - Readout: replacements reuse existing RO

Possible Applications

- sPHENIX Midrapidity upgrades with GEM-layers
 - **Cylindrical GEM electrodes ?**
 - Length and radii
 - **HBD type modules ?**
 - **Readout**
 - Strips: lower number of RO channels, multiplicity
 - Pixel: integrated CMOS
 - **Precision**
 - Strips $\sim 100 \mu\text{m}$
 - Pixel $< 100 \mu\text{m}$
- **TPC-like Drift detectors ?**

Possible Applications

- sPHENIX Forward upgrades with GEM-layers
 - Circularly shaped detector
 - Four layers each side
 - Strip or pixel readout
 - Size issues

Costs for GEM foils (based on ~\$5k / m²):

- ~ \$270k (Forward)
- ~ \$170k (Midrapidity)

Summary

- Development of MPGD rather advanced
- High flexibility and high performance
- High resolution
- Low material budget
- Attractive alternative to Silicon
- Solutions for PHENIX / sPHENIX upgrades to be studied
- R&D for large area implementation
- Significant GEM experience existing within PHENIX (HBD)
- Cost decreasing due to transfer of MPGD production to industry

Possible Applications

Survey of existing conventional readout systems:
GASSIPLEX, ASDQ, CARIOCA, ALTRO, SUPER ALTRO; APV, VFAT

Name	Exp.	Det.	#ch	Shaper (ns)	Noise	Range (fC)	Pol.	ADC	f (MHz)	P/ch. (mW)	Feat.	Tech	Rad hard
APV25	CMS	Si strip	128	50	270+38e/pF	20	both	A	40	2.7	PD, PR	0.25 CMOS	10
AFTER	T2K	TPC	72	100-2000 s-gauss	(350-1800) + (22-1.8)e/pF	19	both	A	1-50 (100)	7.5	VG, VS	0.35 CMOS	no
MSGROC	DETNI	Gas strip	32	T: 25 E: 85	2000e @ 40pF	800	both	A, 1	2ns TDC		VG, ZS	0.35 CMOS	no
Beetle	LHCb		128	25	500+50e/pF	17.5	both	A/1	40	5.2	F-OR	0.25 CMOS	40
VFAT	TOTEM		128	22	650+50e/pF	18.5 (cal) 2000	both	1	40	4.47	F-OR	0.25 CMOS	50
NINO	ALICE	TPC	8	1	1900+165/pF th<100		both	1	async	30	BR	0.25 CMOS	no
CARIOCA	LHCb	MWPC	8	<15 @ 220pF	2000+40e/pF	250	both	1	async	46	BR	0.25 CMOS	20
PASA+ ALTRO	ALICE TPC		16	190 _{nhm} s-gauss	570e @ 20 pF	160	both	10	20	< 40	BC, TC, 0.35, 0.25	25 CMOS	
SVX4	CDF, DO	Sistrip	128	100-360	410+45e/pF	60fC	neg	B	106 (212)	2	ZS	0.25 CMOS	20
SPIROC	ILC, T2K	SIPM	36	A: 25-175 T: 10	A: 1/11pe; T: 1/24pe	2000 pe	neg	8-12	100ps	0.025	dual-TDC pulse gain	0.35 SiGe	no

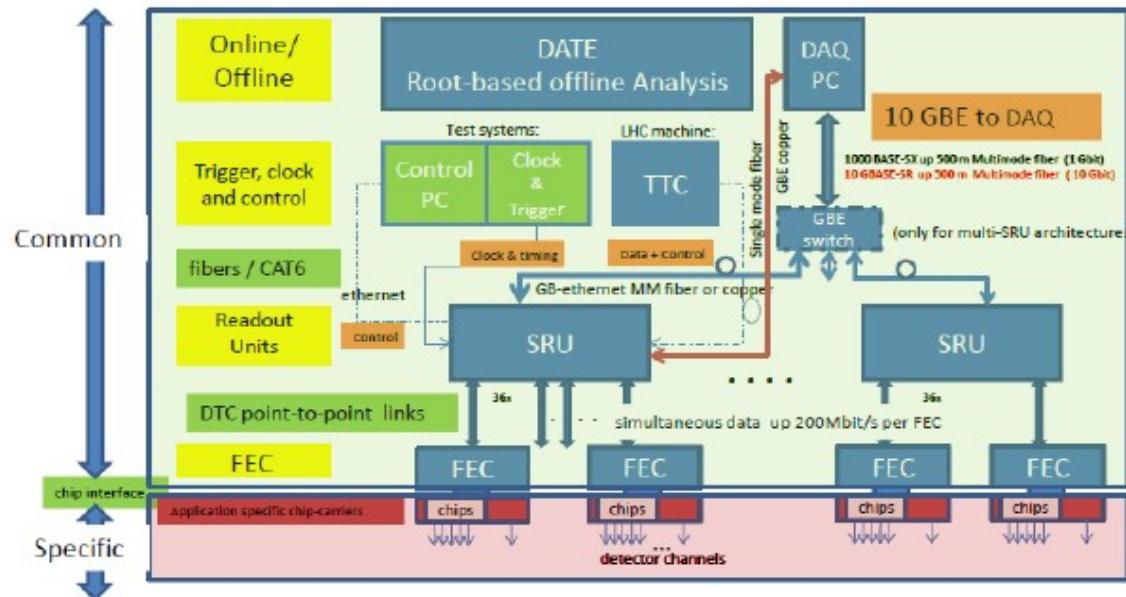
Legend: PD = peak detection, PR = pile-up rejection, VG = variable gain, VS = variable shaping, F-OR = fast-OR, BR = baseline restorer, BC = baseline correction, TC = tail correction, DC = data compression, ZS = zero suppression

- shaping time: 5ns .. 1us
- dynamic range: <100fC
- power: < 10 mW/ch (?)
- ADC accuracy: 10 bits (?)
- TDC accuracy: 1ns

... From Chip Matrix to the "Ideal MPGD Chip" → develop 2-3 chip concepts for the MPGDs

We need an **APV25** chip with variable gain and shaping time like the **AFTER** chip, dynamic range like **MSGROC**, integrated fast-OR like **Beetle**, integrated ADC like **SVX4**, digital signal processor like **ALTRO**

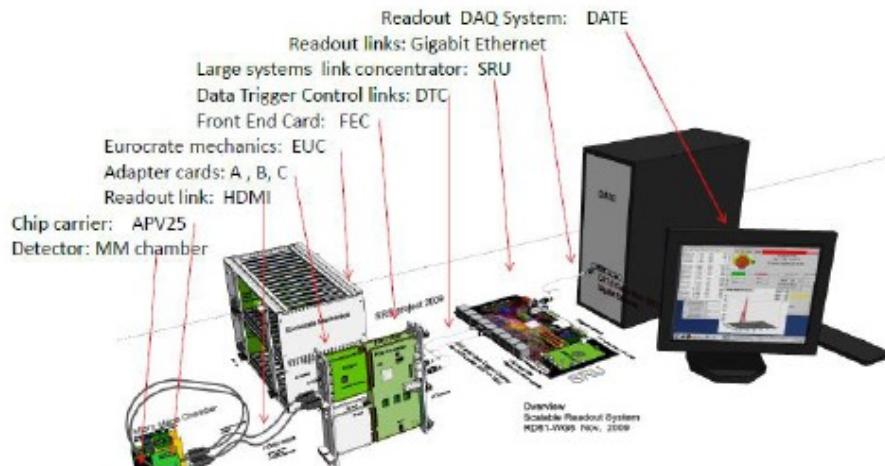
Possible Applications



"RD51 Common Project"
(financed by the RD51) →

First prototype system
to be ready in June 2010

- Scalability from small to large system
- Common interface for replacing the chip frontend
- Integration of proven and commercial solutions for a minimum of development
- Default availability of a very robust and supported DAQ software package.



Possible Applications

TimePix-2

Medipix-1

Medipix-2 250 nm technology

TimePix

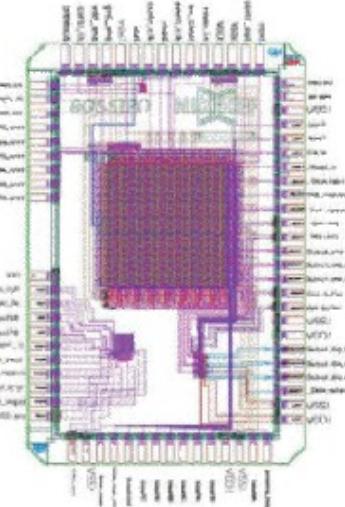
Medipix-3 130 nm technology

TimePix-2

Gossipo-2 MPW

600 MHz osc
in each pixel

Low-noise,
low power analog
input



TimePix-2:

- TDC per pixel: $\sigma = 1 \text{ ns}$
- 'ADC' per pixel: TimeOverThreshold
- noise: 80 e- eq.
- discharge protection circuit
- fast (trigger enabled) readout

Essentially ALL info on primary electrons in gas is extracted!

Possible Applications

At LHC:

- ALICE – THGEM photon-detector
- ATLAS – MicroMegas (muon)
- LHCb – GEM (muon)
- CMS - GEM (muon)

Elsewhere:

- JLAB – GEM and MicroMegas
- KLOE2 – GEM tracker
- ILC TPC – Micromegas and GEM
- ILC DHCAL – Micromegas and GEM
- PANDA – GEM tracker
- PHENIX and STAR – GEM tracker